The Untapped Potential of Solar Panels: A Research Paper to Make Electricity More Affordable and Environmentally-Friendly

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With the innovation of solar panels, many homes around the world can now make electricity at their own house, saving them money and reducing harmful carbon dioxide emissions from entering the atmosphere. But there are still ways to increase the productivity of solar panels, along with all the benefits they bring. My solution to this issue is a new electricity billing plan that uses predicted weather data and average electricity consumption in California, the state I live in, to predict days in which solar energy is high. During these days, the model will send a notification out to customers, telling them that electricity prices will be decreased during certain times of the day because of excess electricity produced by solar panels. This allows customers to put off high-electricity activities such as washing clothes when electricity is cheaper, saving them money and using more solar panel generated electricity than before. The data I used in this research paper includes Accuweather’s weather forecasts, PG&E’s electricity data, and various other sources to calculate solar panel production. Using this plan, we can greatly increase solar panel productivity, reduce electricity costs, and reduce harmful greenhouse gasses contributing to the never-ending climate change.

Global warming is currently one of the biggest issues worldwide. According to NASA, the effects of climate change include glaciers melting, geographic ranges changing, and irregular plant growth (“The Effects of Climate”). These problems may seem small at first, but they are leading to much more severe issues such as rising sea levels, loss in agriculture production, and the destruction of valuable ecosystems (“The Effects of Climate”). Society needs to act fast in order to save the planet and keep it healthy for the generations to come. One way we can do this is targeting one of the main contributors to global warming, greenhouse gas emissions. One of the biggest contributors to these harmful emissions, right behind transportation, is electricity production (“Sources of Greenhouse Gas Emissions”). After its invention, electricity has become a staple to society and powers most of the appliances we use today. This energy source comes with a price, and according to the United States Environmental Protection Agency (EPA), a massive 25% of the total greenhouse gas emissions in 2021 in the United States were from electricity production (Fig. 1). This number will surely increase in 2023 with more and more people transitioning to electric vehicles and appliances worldwide.

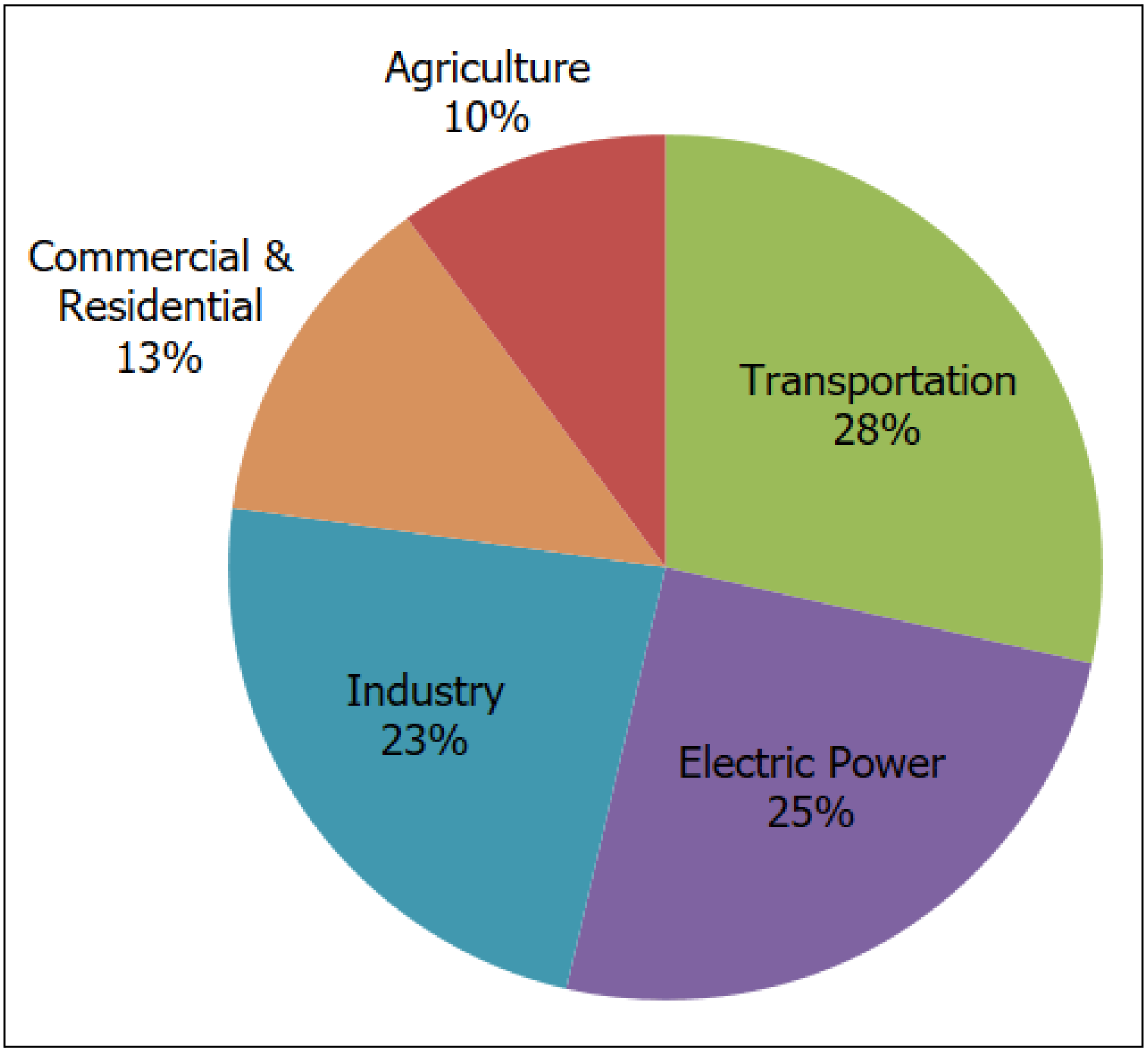

Fig. 1. A chart showing the distribution of greenhouse gas emissions(CO_2) by major sectors of the economy by the end of 2021("Sources of Greenhouse Gas Emissions").

We need a robust alternative method of producing electricity that does not require fossil fuels and is reliable enough to power a heavily electric-dependent society, and this alternative is solar power. Of course, many people know that solar panels are already being used today to produce electricity and have helped reduce the use of fossil fuels. According to the Columbia Climate School, an acre of solar panels in Virginia helps reduce more than 130 metric tons of CO_2 emissions every year (Einsenson).

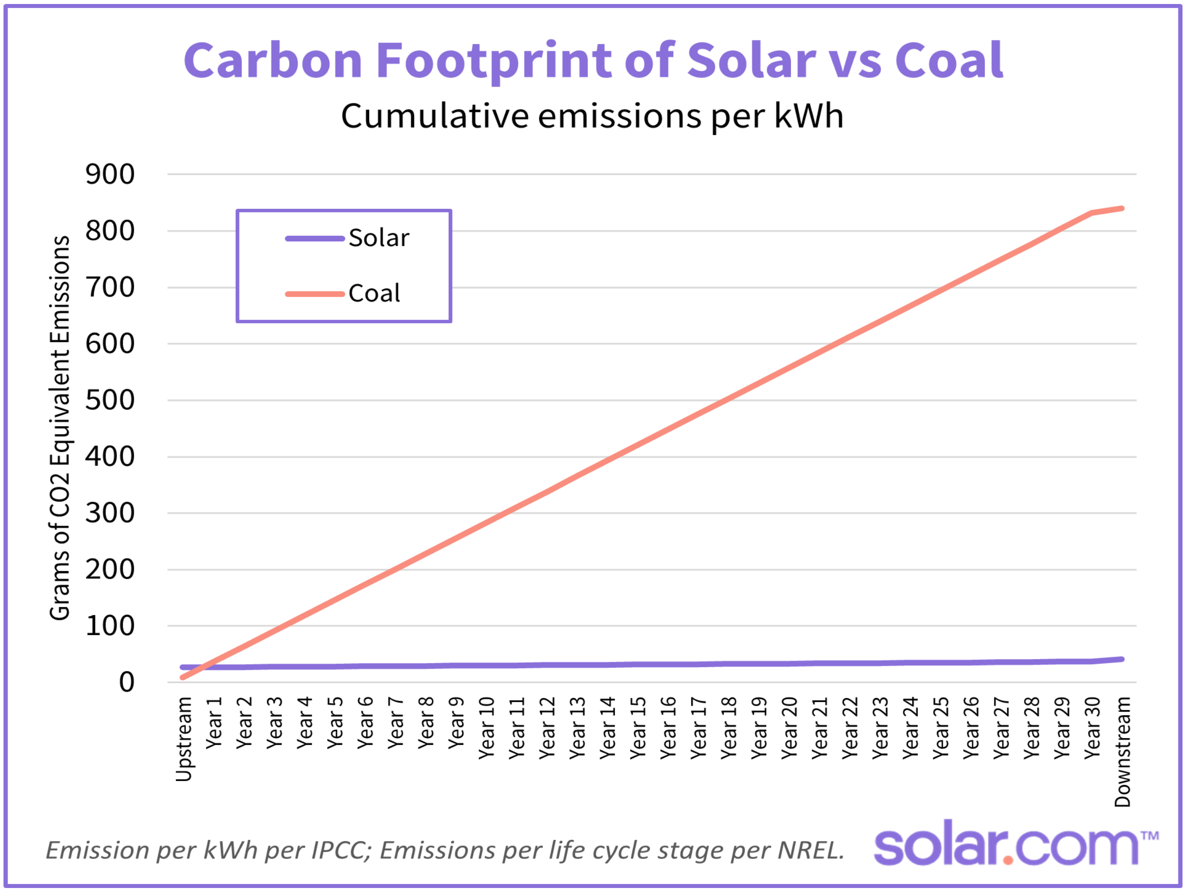

Fig. 2. A line graph showcasing the enormous reduction in carbon footprint that solar energy provides when compared with coal.

However, many do not realize that solar panels are far from being used to their full potential. For example, PG&Edoes not incorporate the electricity production of solar panels at all in their electricity billing plan, and goes off of a simple day-night cycle ("PG&E's Time-of-Use Rate Plans).. If PG&E integrated solar panel-produced electricity and weather conditions in their billing, it would allow solar panels to be used to their fullest potential and greatly decrease the need for fossil fuel-powered electricity.

The goal of the study is to describe how to take advantage of the excess electricity being produced by solar panels on residential homes and use it to both lower the cost of electricity for consumers as well as mitigate global warming by increasing the use of renewable energy sources. These goals can be achieved by creating a new billing plan which, unlike the current day-night plan used by PG&E, will use future weather data and the number of solar panels in the area to use solar-panel produced electricity more efficiently.

The question this project intends to answer is simple: How much money can the average household save by incorporating the amount of sunlight available during the day into the billing of electricity instead of the standard day-night cycle followed today? I rely on multiple data sources to build a model. I also chose to focus on the state I live in, California, and the eclectic company my family and my neighbors use, PG&E, for my project.

First, I hoped to utilize weather data to better incorporate predictions of the weather up to a week in advance. This information would allow the model to select dates with the best weather conditions for solar panel electricity production. Contrary to popular opinion, solar panels do not perform their best when the weather is especially hot. It is a commonly held belief that simply the hotter the weather is, the more electricity solar panels produce because of the surplus of sunlight. However, in actuality, solar panels decrease in efficiency and electricity production when the weather goes above their optimal temperature ("Temperature Coefficient and Solar Panels: All You Need to Know"). According to LG Solar, every solar panel has a measurement called the temperature coefficient. This measurement dictates the decrease in efficiency from its Pmax (rated maximum power) for every degree in celsius the temperature goes above the solar panel's ideal conditions ("Temperature Coefficient and Solar Panels: All You Need to Know").

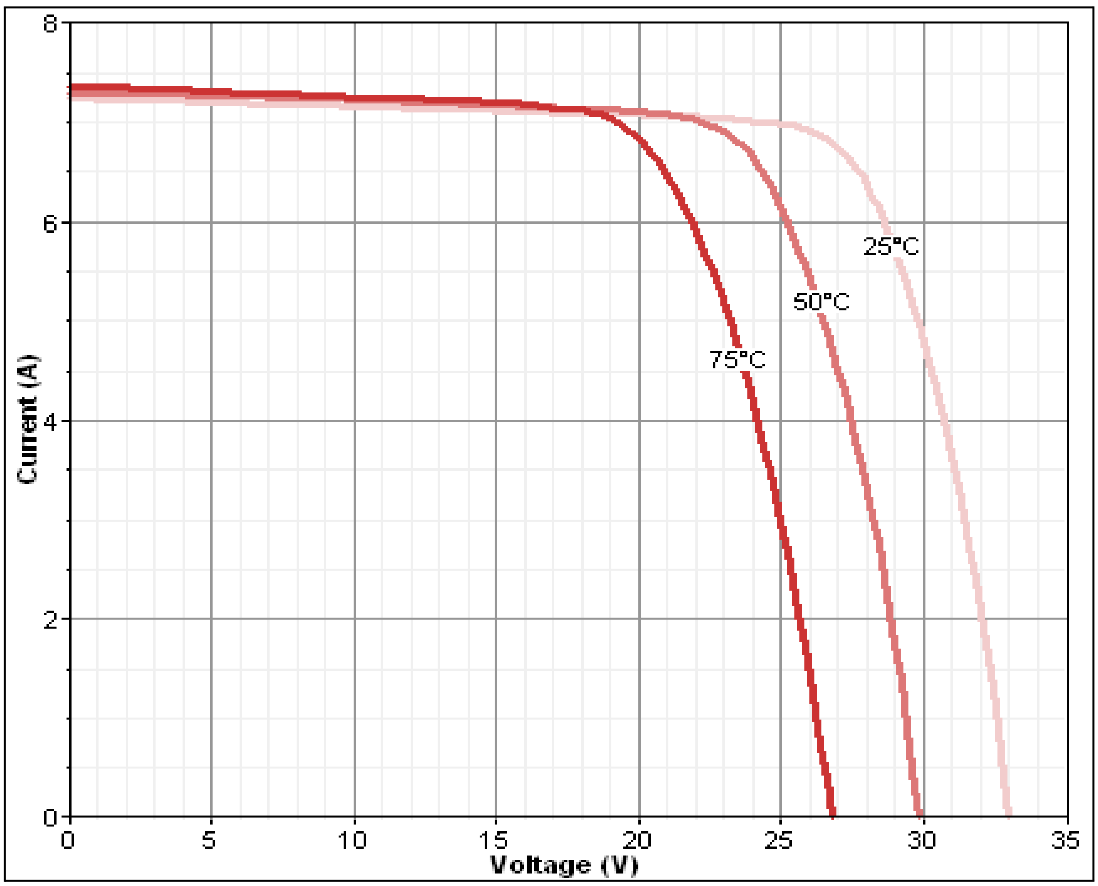

Fig. 3. A graph that details the decrease in voltage and in turn solar panel electricity production that higher temperatures cause.

Using these metrics of solar panel energy output and the types of solar panels that are the most common in California households, I gathered the data needed for this experiment. Along with these solar panel metrics, I also needed the data of weather patterns and sunlight of at least a week ahead. This is needed for my model because the goal is to notify customers of days with high solar panel output, which will motivate customers to hold off high-electricity tasks such as using their washing machine for those days with high energy output and lower cost. If we do not have the data of the weather in the future, we will not be able to notify customers while still giving them time to plan ahead.

Next, I determined how much electricity PG&E's customers in California used per household by looking at company records. With this number, I was able to run simulations of our model in different days and different conditions while calculating how much electricity is generated compared to how much electricity an average household uses. Based on this data, I could determine exactly how much additional electricity is being generated, and in turn, by how much I can reduce the cost of electricity in these times. With this I can determine exactly how useful our model is and how effective it will be in the real world in terms of customer usage and environmental benefit.

The data I wanted to get out of my research was the weather patterns of at least a week ahead, the average electricity consumption of an average household in California, and the average electricity production of a household solar panel. Unfortunately, through all my research, I was not able to find an accurate and usable ratio between houses with solar panels and houses without in a certain area, which would have allowed us to determine how much of the surplus electricity can be used for the whole area. I also was not able to find a weather application that gave me the exact levels of sunlight on specific instead of estimates such as sunny, mostly sunny, etc.

According to the data I was able to gather, I constructed the variables needed for the model. The first variable in the model that I constructed was the days which the proper weather conditions were met. According to Architectural Digest, as of 2023 the most common type of solar panels used in California households are monocrystalline solar panels. This is due to the very long lifespan, high efficiency, and eco-friendliness of these solar panels (Hawkins). I decided to continue building the model with monocrystalline solar panels as the panels used. Having monocrystalline panels as the base, I could now calculate the measurements needed to determine how much electricity the panels could produce at different conditions. As stated on Tindo Solar, the temperature coefficient of a monocrystalline solar panel is -0.5% per degree celsius above the most optimal temperature of the panel, being 25 degrees celsius ("Temperature Coefficient"). Additionally, I selected a weather forecast organization called Accuweather, which gives detailed hour-to-hour reports of the temperatures of three days ahead, as well as an overall temperature for the entire day up to a month ahead ("Latest Study of 120 Million Forecasts Proves AccuWeather Forecasts Are Most Accurate"). Of course, the accuracy of the weather conditions decreased when looking many weeks into the future. However, the model can still mark dates which are predicted to have favorable circumstances and keep them in check, so when the date gets nearer and the accuracy of its weather forecast increases in accuracy, the model will be prepared to make any necessary changes. With all these components, including the fact that the state of California has more than 3,000 hours of annual sunlight hours, which translates to 8-9 hours a day, I was able to proceed with our calculations ("Average Annual Sunshine").

The second data variable in the model will be the daily household usage of electricity versus the electricity output of solar panels when the weather conditions are favorable. The first data point I was able to gather was the yearly energy consumption of an average California household, which is 9,000 kwh ("Electricity Usage"). This translated into 24.65 kwh daily used by an average household, and this is the number I plugged into the model. Next I gathered the electricity output of monocrystalline solar panels at their pmax, which is around 0.3 kWh per solar panel ("How Much Power"). Then I calculated the number of solar panels required to supply enough power to offset the 9,000 kWh, which is around 10 panels.

Using these two variables, I was able to take a sample week of temperatures in California and calculate exactly how much electricity surplus was generated. The calculations for this data are in the table below.

Date	Time	Temperature:	Equation:	reduction in efficiency	panel adjusted output (kV	power produced per hour (kWh)	Electricity Surplus
8/12/2023	12:00 PM	27	(1.027)-(10*(0.3*0.99)	0.01	0.297	2.97	1.943
8/12/2023	1:00 PM	29	(1.027)-(10*(0.3*0.98)	0.02	0.294	2.94	1.913
8/12/2023	2:00 PM	30	(1.027)-(10*(0.3*0.975)	0.025	0.2925	2.925	1.898
8/12/2023	3:00 PM	32	(1.027)-(10*(0.3*0.965)	0.035	0.2895	2.895	1.868
8/12/2023	4:00 PM	31	(1.027)-(10*(0.3*0.97)	0.03	0.291	2.91	1.883
8/12/2023	5:00 PM	30	(1.027)-(10*(0.3*0.975)	0.025	0.2925	2.925	1.898
8/12/2023	6:00 PM	29	(1.027)-(10*(0.3*0.98)	0.02	0.294	2.94	1.913
8/12/2023	7:00 PM	27	(1.027)-(10*(0.3*0.99)	0.01	0.297	2.97	1.943
8/12/2023	8:00 PM	26	(1.027)-(10*(0.3*0.995)	0.005	0.2985	2.985	1.958

Fig. 4. A data table made to show how much additional electricity is generated on August 12th, 2023 from 12:00 PM to 8:00 PM.

As seen in the data table, there is an electricity surplus of almost two kwh for every hour on August 12th, 2023. Additionally, this day did not have the best weather conditions for solar panels, and many days in California have closer to nine full hours of sunlight. Given the massive amounts of surplus electricity being generated, it is ideal that we shift our electricity billings to include weather conditions and forecasts so society can take advantage of this electricity and use it more during these times to help mitigate climate change and the lower cost of electricity for consumers.

There were many limitations in this project, which I had to compensate for by making many assumptions in our data. One of these key assumptions I had to make was with our weather data. Although Accuweather is known for its high accuracy and reliability worldwide, it is not accurate enough for estimates of future weather which is key to bringing out this model's true potential. However, I am sure electrical companies such as PG&E have access to better weather forecast systems that are not available to the public, which can make this model much more accurate.

This model makes it clear just how much potential solar energy is being wasted in households, and the advantages brought by a weather-dependent electricity billing cycle are too beneficial to ignore. It helps customers by letting them save their high-electricity applications for times of electricity surplus, while also helping the environment by using more solar-panel generated electricity than before. Although my focus for this project was the state of California, this new billing cycle for electricity will be useful for any household in any part of the world, and the benefits will follow.

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