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How the angle of the sun affects the energy output of solar panels.

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## Abstract

This experiment was made to answer the question, “how does the angle of the sun affect the energy output of solar panels?” My hypothesis was that as the angle of the sun increased, energy output of the solar panels would increase and as angle of the sun decreased, energy output of the solar panels would decrease. To do this experiment, I used solar panels that were mounted on the roof of my house, and two apps, Suncalc.org and monitoring.solaredge.com. These apps were used to check the angle of the sun, and the Kwh produced. For the first round I did an ANOVA test, which came out as significant. The Tukey HSD results were all significant except for 1 treatment pair. For round 2 I did a correlation coefficient test which is better for this type of experiment. The results said that there were no significant relationships between X and y variables (angle of the sun values and Kwh values). My hypothesis was partially supported by my data, the first round of the experiment gave me data that supports a hypothesis. But the second round of experiments did not support my hypothesis because there seemed to be no correlation between the angle of the sun and Kwh produced.

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Researchable question:

How does the angle of the sun affect the energy output of solar panels?

Hypothesis

as the angle of the sun increased, energy output of the solar panels would increase and as angle of the sun decreased, energy output of the solar panels would decrease

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## Background information

Energy is important for modern day life, an example of this is the U.S. Consumes around 81,642 kWh/capita per hour (Jager 20). Solar energy has proven to be one of the most popular and widespread sources of renewable energy. The reason I chose to do this project is I thought it could be helpful in real world situations or at least be used for something related to gathering more energy so that we can eventually move on from fossil fuels. Usually solar panels are used to create energy to power houses, schools, or even parts of cities. Many experiments have been done to test solar panels or compare two types of solar panels, or to see if solar panels are a viable option in certain areas or places. Solar panels are quite complicated in how they work, first photons release valence electrons on impact. Which makes the electron create a small electric current, which makes electricity. This is a very simplified description of how solar panels work and different solar panels might work in different ways. Although there are no experiments that I can find on the specific question I am asking, there are experiments trying to find the optimal tilt angle for solar panels to get the maximum amount of solar radiation. For example, an experiment done by Sethi, Sumathy, Yuvrajan, and Pal finds the maximum energy output at multiple latitudes influenced by the swing angle of the sun. They found out that less energy was gathered by a solar panel during months that did not have as much direct sunlight compared to months that did. Another experiment done by Roshan R. Rao, H. R. Swetha, J. Srinivasan, and Sheela K. Ramasesha compares two different solar panels, one on a fixed axis at 13 degree north

latitude and the other on a dual axis tracker, which is technology that is used to track the sun. d the results were the panels on a dual axis tracker generated 21% more electricity compared to the fixed solar panels. This is important to my experiment because it shows the position or angle of the sun does matter when it comes to energy production.

## Materials:

Solar panels

phone / electronic device

My solar edge app

Laptop

Google sheets

## Procedures

1. Log into the My Solar Edge app
2. Look in the top right where it says “production today”, this will give energy made that day.
3. Check for weather, if the sun is blocked for more than 5 hours do not take any data that day

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4. Record the total energy and put the data into one column in google sheets every Monday, Wednesday, and Sunday.
5. On Monday, Wednesday, and Sunday, measure the angle of the sun using shadows, this is done with a ruler and then take the vertical measurement and divide it by the shadow measurement, ('b' divided by 'a') at the exact same time everyday, at 4:30 PM
6. Put the angle of the sun in google sheets in a separate column
7. Every Sunday, average the amount of energy made by the solar panels using the data collected, this is done using the google sheets function "average" and selecting the 4 values, this will average the values.
8. I Averaged the angle of the sun the same way I averaged the energy output.
9. Compare how much the angle of the sun either increased or decreased to the percent change overtime for energy output.

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Summary tables

**1st round**

| Summary table | Angle of the sun averages | Energy produced kWh on average |
|---|---|---|
| | 43.0175 | 44.86 |
| | 40.82 | 39.99 |
| | 38.3 | |
| | 37.6 | |
| Standard deviations: | 2.477261908 | 3.443610024 |

**2nd round**

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| Summary table | Angle of sun averages: | Kwh's produced |
|---|---|---|
| | 73.62333333 | 59.38333333 |
| | 75.53666667 | 65.35 |
| | 77.21666667 | 66.12 |
| | 78.64333333 | 68.28666667 |
| | 80.66666667 | 58.24333333 |
| | 81.18 | 65.76333333 |
| | 81.36333333 | 59.70333333 |
| | 81.19 | 58.17666667 |
| | 2.959012464 | 4.133061435 |

## Graphs

1st round

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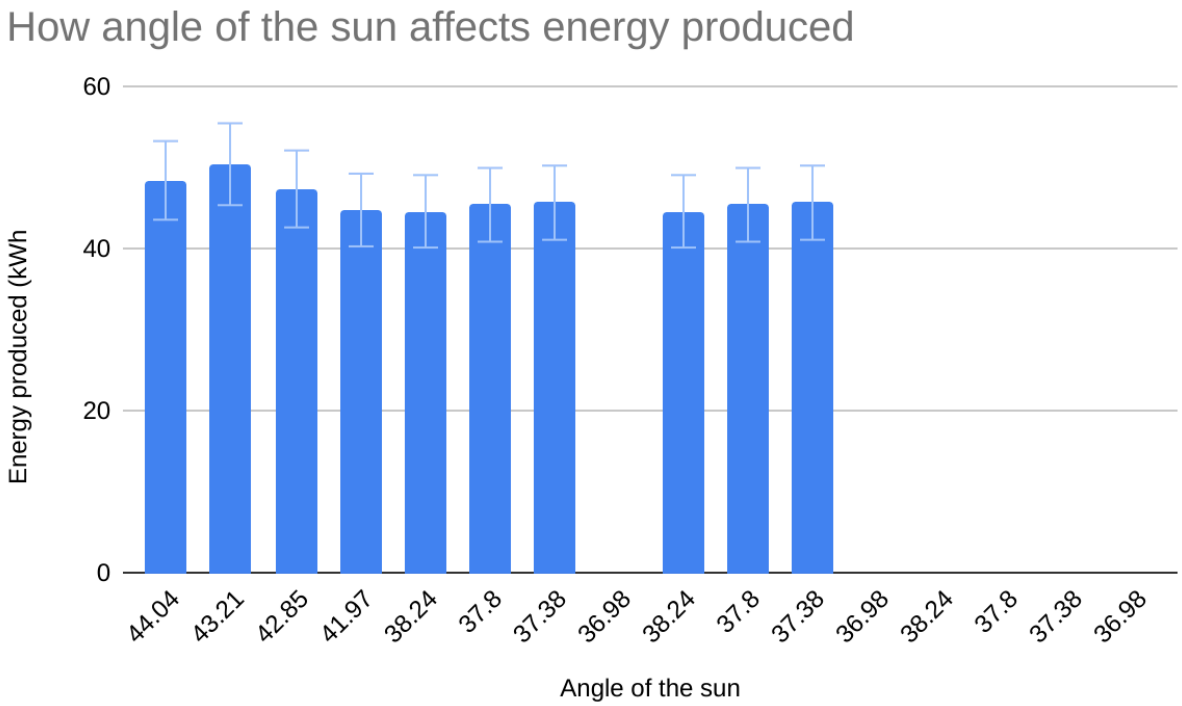


2nd round

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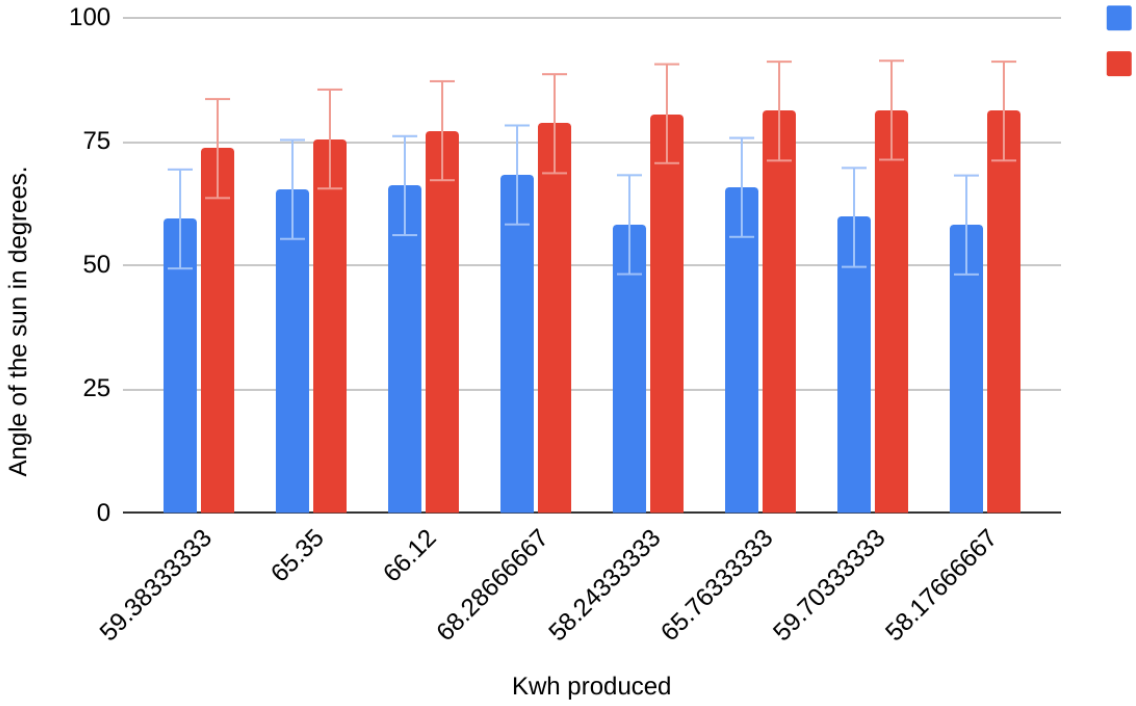
**(red bars are angle of the sun. Blue bars are Kwh's produced.**




***One-way ANOVA of your $k$=4 independent treatments:***

| source | sum of squares SS | degrees of freedom $\nu$ | mean square MS | F statistic | p-value |
|---|---|---|---|---|---|
| treatment | 73.6419 | 3 | 24.5473 | 28.6164 | 9.4378e-06 |
| error | 10.2937 | 12 | 0.8578 | | |
| total | 83.9356 | 15 | | | |

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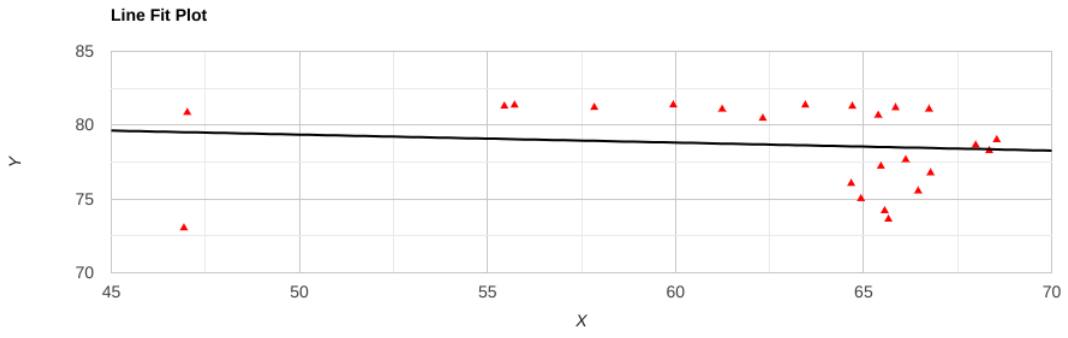
**Tukey HSD results**

| treatments pair | Tukey HSD Q statistic | Tukey HSD p-value | Tukey HSD inferfence |
|---|---|---|---|
| A vs B | 5.4417 | 0.0107711 | * p<0.05 |
| A vs C | 10.1870 | 0.0010053 | ** p<0.01 |
| A vs D | 1.5116 | 0.6979806 | insignificant |
| B vs C | 4.7453 | 0.0255049 | * p<0.05 |
| B vs D | 6.9533 | 0.0017425 | ** p<0.01 |
| C vs D | 11.6986 | 0.0010053 | ** p<0.01 |

Correlation coefficient test

Results of the pearson correlation indicated that there is a non significant small negative relationship between X and Y, ($r(22) = .115$, $p = .593$).

⇩ r = -0.1149



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# Conclusion

The p value from the ANOVA test in round 1 was less than 5% showing there was not a variance in data. The tukey hsd results also showed the data was significant. But compared to the second round where the correlation coefficient test showed that there was no correlation between angle of the sun and Kwh produced which said that my experiment had no correlation. My hypothesis was not supported by this or the graphs. The first graph showed that there was an upward trend in both angle of the sun and Kwh produced and that they did correspond to each other. But on the second graph there was no correlation at all between the two variables on the graph. Overall I think my conclusion was kind of supported by my data but the differing results in the first and second rounds means it was not fully supported.

Overall the experiment could have gone better because the website was down and other minor problems. I could have kept better track of things like weather and overall it was sometimes kind of a mess because of the website. The website used to track Kwh produced was often down or had very different results for how much energy was produced on certain days. If I did this experiment again I would have found a different way to measure Kwh or done the experiment completely differently because it was sometimes very difficult to get data. I learned that my hypothesis was most likely correct about my question and there are experiments related to it that do provide evidence that my hypothesis was correct.

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Appendix

1st table

| Week 1 | Monday | wednesday | Friday | Sunday | averages | standard deviations |
|---|---|---|---|---|---|---|
| Angle of the sun | 44.04 | 43.21 | 42.85 | 41.97 | 43.0175 | 0.742945994 |
| Energy produced (kWh) | 48.51 | 50.51 | 47.46 | 44.86 | 47.835 | 2.037308273 |
| | | | | | | |
| | | | | | | |
| Week 2 | 41.67 | 41.09 | 40.53 | 39.99 | 40.82 | 0.6261788882 |
| | 44.7 | 45.5 | 45.76 | no data | 45.32 | 0.4510727953 |
| | | | | | | |
| Week 3 | 39.72 | 39.21 | 37.33 | 36.94 | 38.3 | 1.186907747 |
| | no data | no data | no data | no data | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| Week 4 | 38.24 | 37.8 | 37.38 | 36.98 | 37.6 | 0.4696807426 |
| | no data | no data | no data | no data | | |

2nd table

| | Monday | Wednesday | Friday |
|---|---|---|---|
| Kwh produced | 62.32 | 65.39 | 47.02 |
| angle of the sun | 80.47 | 80.67 | 80.86 |
| | | | |
| | | | |
| Kwh produced | 66.74 | 65.85 | 64.7 |
| angle of the sun | 81.08 | 81.18 | 81.28 |
| | | | |
| | | | |
| Kwh produced | 55.72 | 59.94 | 63.45 |
| angle of the sun | 81.36 | 81.37 | 81.36 |
| | | | |
| | | | |
| Kwh produced | 55.45 | 57.84 | 61.24 |
| angle of the sun | 81.29 | 81.2 | 81.08 |
| | | | |

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| | | | |
|---|---|---|---|
| Kwh produced | 46.93 | 65.66 | 65.56 |
| angle of the sun | 73.04 | 73.63 | 74.2 |
| | | | |
| Kwh produced | 64.93 | 66.45 | 64.67 |
| angle of the sun | 75.02 | 75.54 | 76.05 |
| | | | |
| Kwh | 66.78 | 65.46 | 66.12 |
| Agle | 76.77 | 77.22 | 77.66 |
| | | | |
| Kwh | 68.34 | 67.98 | 68.54 |
| angle | 78.27 | 78.65 | 79.01 |
| | | | |