The Effects of Temperature and Cloud Coverage on Solar Kwh Output

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Abstract

This study investigates the relationships among air temperature, PM 2.5 concentration, cloud coverage, surface solar irradiance, and the performance of photovoltaic (PV) systems. The team conducted research and collected data for about 6 weeks before they had enough data to make informed observations. They used the APSystems solar website linked to TTAoE's solar panels to measure the Kwh output of the panels and the solar irradiance at our location at a precise time every day. The AP solar website records the daily energy produced by the solar panels and the measurement of surface irradiance they detect and absorb for energy. The team that measured air quality conditions shared their Purple Air data, given to them from the UT Purple Airlink Sensor. Using this data and physical observations, they can confirm there are clear connections between the solar team's variables and solar irradiance. The research confirms that solar irradiance is the primary driver of PV output, as high values directly correlate to higher energy production. Greater cloud coverage and higher PM 2.5 values correlated strongly with reduced irradiance. Higher air temperatures did not decrease the irradiance value. However, the panels did suffer a small energy conversion loss.

Introduction

Surface solar irradiance is the power from the sun in sunlight, and it plays a crucial role in our planet's energy balance. The amount and type of irradiance that reaches the ground is highly variable. Scientists Mol, W., and van Heerwaarden, C. say, "The quality of solar irradiance, namely the amount of diffuse (i.e., scattered) radiation and spectral composition, is also influenced by clouds." Irradiance and cloudiness have an extremely complex relationship, including multiple components that could intensify or reduce irradiance. Mol W and van Heerwaarden stated, "We provide a framework for understanding the vast diversity and complexity found in surface solar irradiance and cloudiness." This project, like others in the past, focuses on energy yield projects in hopes of maximizing efficiency, for example. They'll also compare the correlation between temperature and the daily kWh power production of TTAoE's solar panels. The team's research question is: how do different atmospheric conditions affect surface solar irradiance and the kW output of (PV) Photovoltaic systems?

Hypothesis

An increased AQI, higher air temperatures (above 77 degrees), and greater cloud coverage will all lead to a decrease in solar irradiance, which would reduce the kWh output of PV systems. A high level of particulates (AQI) would absorb more sunlight, reducing the solar energy reaching the panels. Depending on the temperature, more or less AQI particulates could be present. Looking at the data collected, the evidence points to the fact that higher temperatures often result in a lower energy output.

Objective

To observe, record, and hopefully discover the effects atmospheric conditions like cloud coverage, temperature, and particulate matter (2.5) have on surface solar irradiance and the power produced by the solar panels measured in kilowatts.

Methods

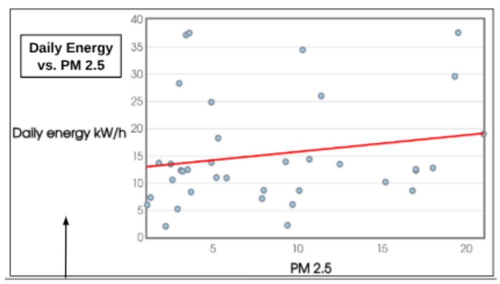
To begin, bring a LabQuest 3, a pyronometer, an engineering notebook, and a writing instrument. Lay out the instruments flat, sensor pointing upwards, while the Labquest 3 is opened onto the data-taking app. Record at the end of three five-minute intervals for data taking (5-10-15). Record cloud type and coverage using the GLOBE observer app. Record air temperature. Then, using a purple air sensor, collect PM 2.5 data. Load into AP systems to record solar panel data, then log onto Google Sheets to record the data properly. Finally, use the statsblue website to compile the data and organize it. Take the data from the Google Sheets and add it to the Statsblue website under the simple linear regression calculator to make the graphs.

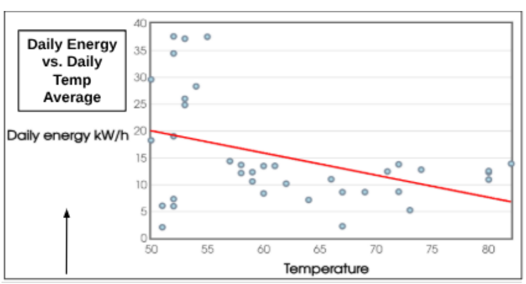
- Bring a LabQuest 3, a Pyranometer, an engineering notebook, and a writing instrument.
- Set up the instruments according to the photo
- Record Irradiance data in 5-minute intervals
- Record cloud type and coverage through the GLOBE observer app on the iPad
- Record the air temperature
- Collect Purple Air PM 2.5 data
- Load into AP systems (Records relevant solar panel data) and transfer data to the Google sheet
- Put the collected data into Google Sheets for organization
- Use the statsblue website to compile data and organize it into graphs

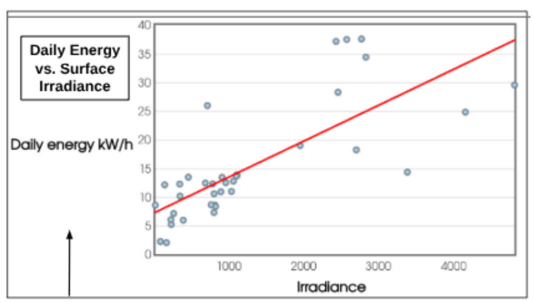
Results

Cloud coverage does have a direct effect on solar irradiance and can either amplify the sun’s energy or trap it behind thicker, opaque clouds. Low-level clouds are often thicker, and they absorb and scatter the sun's light, which reduces our surface irradiance. High-level translucent clouds often amplify solar irradiance through a phenomenon called cloud lensing, in which ice crystals bend or refract light through the cloud down to the surface, intensifying it significantly. The team found that solar panels' energy conversion efficiency tended to decrease when the irradiance values stayed the same at both 70 degrees and 80 degrees. Using the Air quality measurements from some of the high-quality Airlink devices, they were able to observe a small trend in our data. Often, days with a higher PM 2.5 value showed less solar irradiance and fewer Kilowatts of power converted.

Graphs, Photos/maps



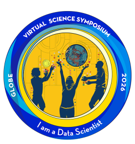




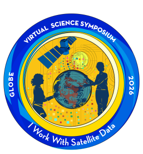
Conclusion

The initial hypothesis was proved correct when comparing the observed data with the theories of scientists researching similar topics about what variables affect solar irradiance. Cloud coverage has a direct effect on solar irradiance, and it can potentially amplify solar irradiance, or thicker opaque clouds could absorb it. In early October, the temperatures were still in the 70-80 degree range, where the team found that the solar panels began to operate less efficiently after just a few days of high temperatures. They went back to optimal power production after a good period of cooling. Measuring the irradiance at the observation location, the amount of power produced, the PM 2.5 value, and the temperature helped them draw clear conclusions about how much solar energy is being converted. This research is something that needs more attention. This team recommends others to do a study like this and collect data for a 3-month-long period every day, once a day, taking note of the cloud coverage and type to try to learn more about the cloud lensing phenomenon. The national environmental satellite, data, and information service says (*Cloudy Days and Solar Arrays*, 2020) “The frozen water molecules inside of high-altitude clouds refracted the sun’s light, which in turn caused brighter-than-normal conditions on the ground compared to the darker blue skies of a clear day. This phenomenon… is called “cloud lensing.” Doing research for this long would also help to make clearer correlation values on the graphs. Visualizing the connection between solar generation and weather patterns allows researchers to plan optimization and make informed predictions about how weather could affect solar panel efficiency.

Badges



The team earned several badges while working on the project; the first was the **“I am a data scientist”** badge, chosen because the irradiance data, taken in tandem with cloud data, helped the team reach their conclusion after months of data collection.



Moving on to the **“I work with satellite data”** badge for the cloud matches we made with NASA’s satellites, the team used these to line up the cloud data for record-keeping. The team had received several notices about the cloud data they had gathered and its match to the atmospheric conditions recorded by the satellite.

Next, the **“I work with a STEM professional”** badge, for having professionals like Dr. Jon Bossenbrook review the poster and data, as well as help from people like Kristina Kania, who assisted with graphing our data and giving additional review, alongside others like Aniya Woodley, Juhti Mitra, and Ted Richardson, who all contributed with their feedback and guidance.

Finally, the **"I am a collaborator"** badge is working with combining research with other teams in our class. We shared both our data and took in theirs to try to draw clearer and cleaner lines between the data we were collecting. We wanted to find the data that had the strongest correlation with our topic so we could draw clear accurate conclusions.

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References

Mol, W., & Chiel van Heerwaarden. (2025). Mechanisms of surface solar irradiance variability under broken clouds. *Atmospheric Chemistry and Physics*, *25*(8), 4419–4441. https://doi.org/10.5194/acp-25-4419-2025

Paszkuta, M., Markowski, M., & Krężel, A. (2024). Empirical Verification of Satellite Data on Solar Radiation and Cloud Cover over the Baltic Sea. *Journal of Atmospheric and Oceanic Technology*, *41*(2), 161–178. https://doi.org/10.1175/jtech-d-23-0061.1

Nevins, M. G., & Apell, J. N. (2021). Emerging investigator series: quantifying the impact of cloud cover on solar irradiance and environmental photodegradation. *Environmental Science: Processes & Impacts*. https://doi.org/10.1039/D1EM00314C

Pfister, G., McKenzie, R. L., Liley, J. B., Thomas, A., Forgan, B. W., & Long, C. N. (2003). Cloud Coverage Based on All-Sky Imaging and Its Impact on Surface Solar Irradiance. *Journal* *of Applied Meteorology and Climatology*, *42*(10), 1421–1434. https://doi.org/10.1175/1520-0450(2003)042%3C1421:CCBOAI%3E2.0.CO;2

Zhang, C., Shen, C., Yang, Q., Wei, S., Lv, G., & Sun, C. (2020). An investigation on the attenuation effect of air pollution on regional solar radiation. *Renewable Energy*, *161*, 570–578. https://doi.org/10.1016/j.renene.2020.07.146

Cloudy Days and Solar Arrays. (2020, June 1). NESDIS. https://www.nesdis.noaa.gov/news/cloudy-days-and-solar-arrays