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, 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 teams 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. says, "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 like NASA's irradiance team, (SIST) focuses on energy yield projects in hopes to maximize efficiency. 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.

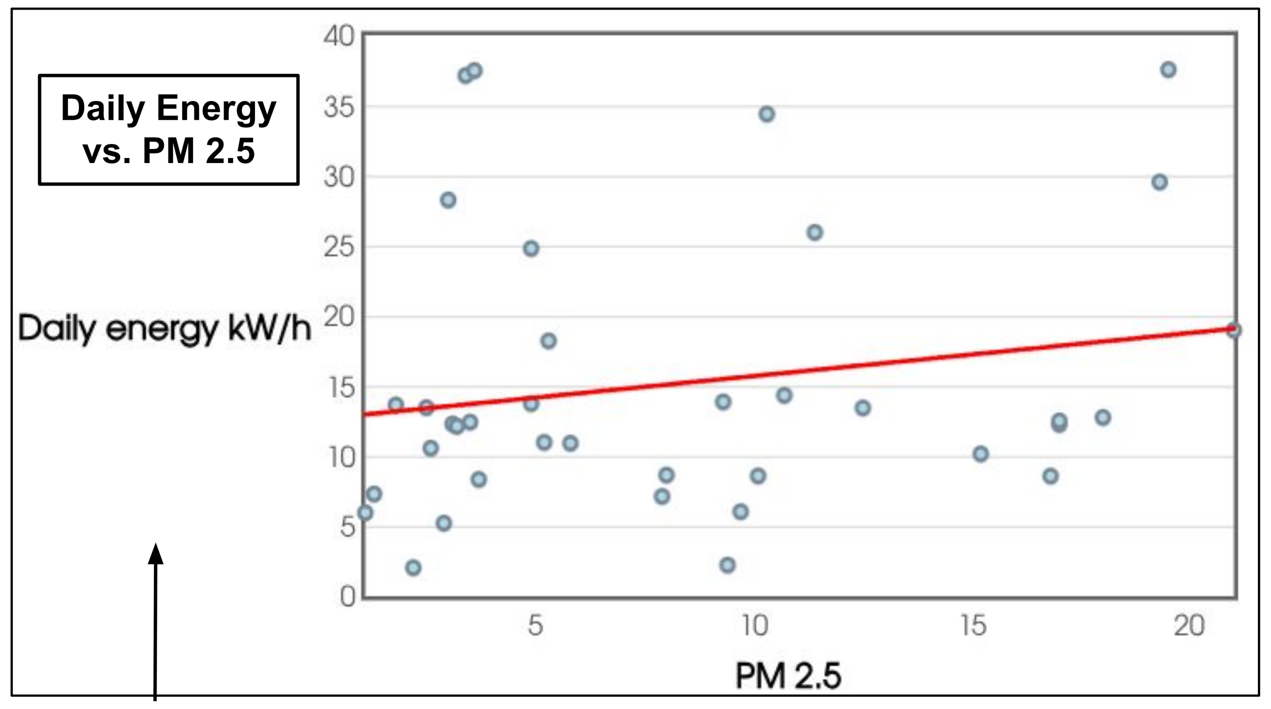
Objective

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.

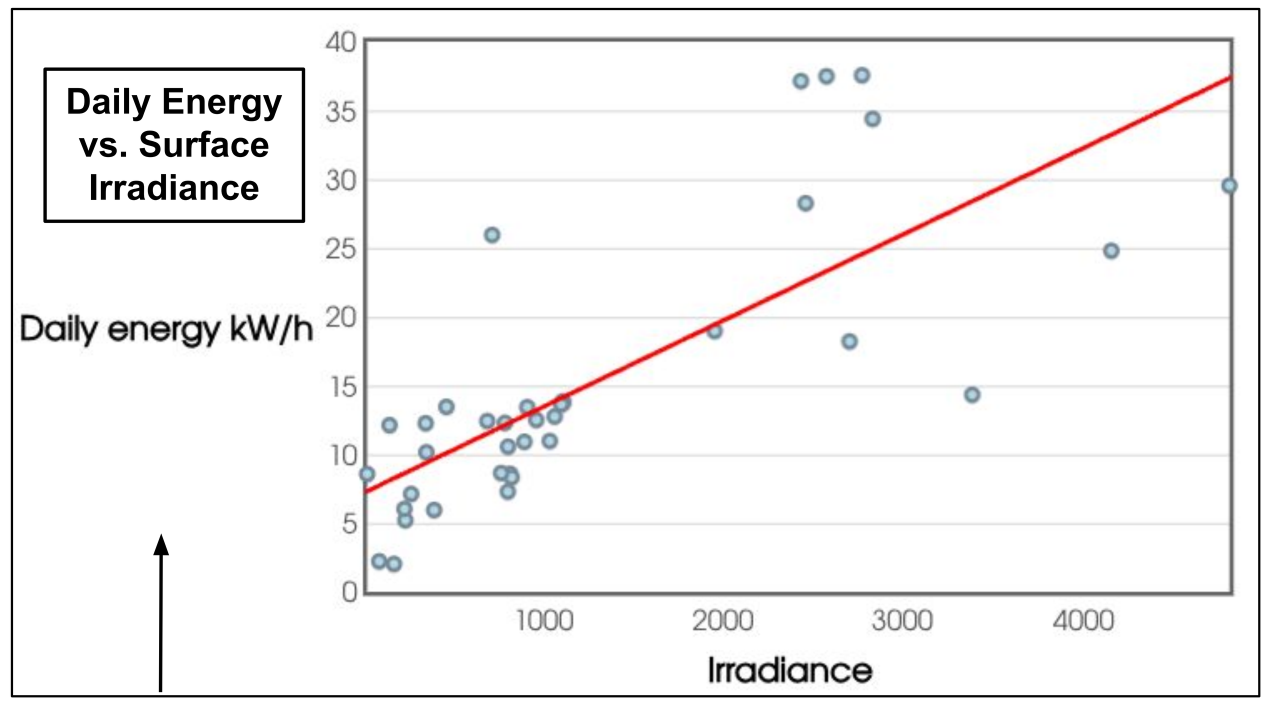
Methods

- Bring a Labquest 3, Pyranometer, Engineering notebook and writing instrument.
- Set up instruments according to 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 collected data into google sheets for organization
- Use the statsblue website to compile data and organize it into graphs

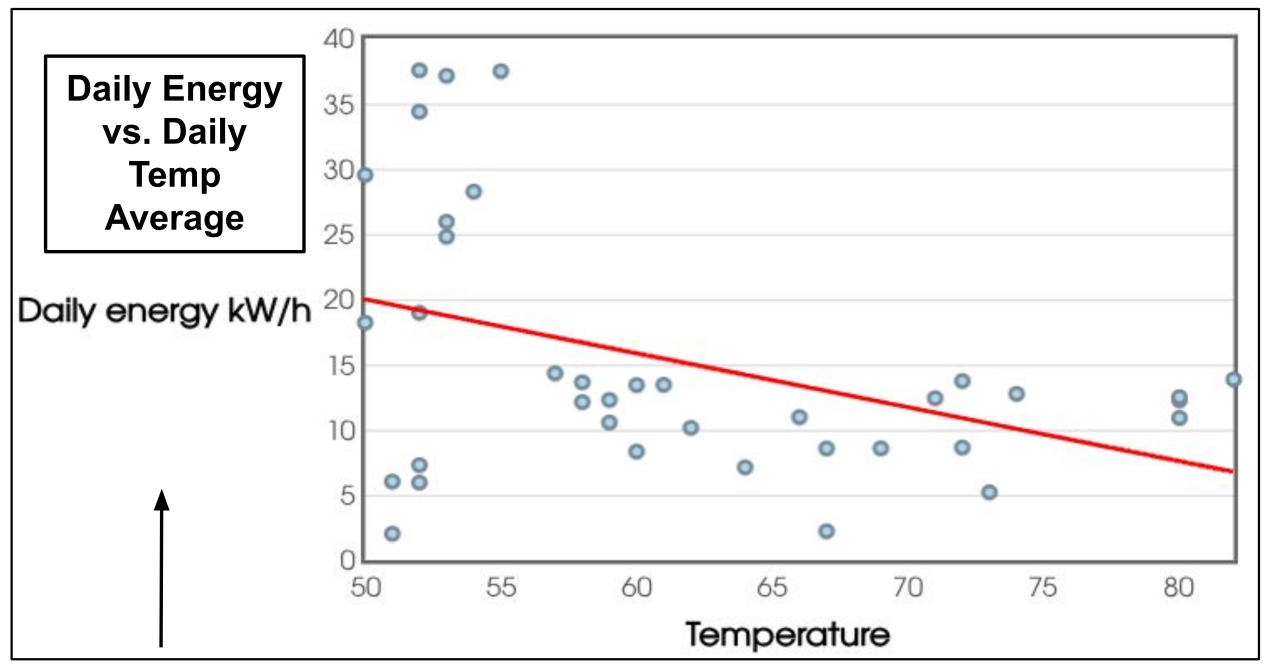
Varying atmospheric conditions correspond with and affect Solar kWh generation and corresponding irradiance



This graph predicts a weak correlation between PM 2.5 and daily energy production. The data does not follow a clear trend and the researcher believe a longer wider study involving particulate matter would be required to better determine its effects.



This graph displays a strong correlation between daily energy and irradiance. An increased amount of power is produced during times of high solar irradiance and it decreases during times of low irradiance.



The daily energy being produced on days with higher temperatures shows a strong correlation between reduced kW production and higher temperatures. Cold weather does not mean solar panels produce less energy, often it the irradiance is significantly higher during these temperature when not disturbed by clouds.

Gabe, Isaiah, and collaborators
- All were on the roof of the EV lab, where the majority of the data collection occurred

This is how we conducted our globe observer app research, by looking t the sky we could se the conditions and record them in the app. We got several satellite matches throughout our researching period which validate our research.

Globe Observer app cloud observation satellite match! The GOES-19 satellite was overhead in the earth's orbit and the teams cloud observations from the ground closely match the atmospheric data the satellite was recording.

GLOBE Cloud Observations Paired with NASA Satellite Data

Total Satellite Comparisons: 41

Useful Resources: How to Read My NASA GLOBE Clouds Satellite Comparison Table, How to Compare My Cloud Observations with Satellite Data, Cloud Cover, Cloud Type, Cloud Opacity, Satellites

Observation	GLOBE	GOES-19 Satellite
Universal Date/Time	2025-11-05 14:55:00	2025-11-05 15:03
Latitude	41.68	41.36 to 42
Longitude	-83.59	-83.91 to -83.27
Total Cloud Cover	Broken (50-90%)	Broken 87.71%
High Clouds	Cirrus Cirrocumulus Cover: Broken (50-90%) Opacity: Translucent	Cover: Broken 82.79% Altitude: 8.15 (km) Phase: Ice/Water Mix 249.23 (K) Opacity: Transparent
Mid Clouds	Cover: Few (<10%) Opacity: Translucent	Cover: Few (4.10%) Altitude: 4.77 (km) Phase: Ice 265.15 (K) Opacity: Transparent
Low Clouds	Stratus	Cover: Few (0.82%) Altitude: 1.7 (km) Phase: Water 277.1 (K) Opacity: Transparent

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 to 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.

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 of the observation location, how much power was being produced, the PM 2.5 value, and the temperature helped them draw clear conclusions between tested variables and 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 everyday, 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 more clear 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.

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