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Evaluating the Solar Power Requirement of the Sensor Nodes

I. Introduction

The *Wireless Sensor Network Project* (*WSN*) is a low-cost monitoring system project for detecting carbon sources in an area. The system uses prototype instruments called *Sensor Nodes*, or *Nodes* for short, containing sensors and electronic modules to measure atmospheric carbon concentrations and wind data. *Nodes* placed in areas with no access to on-grid power require solar energy kits. This evaluation seeks to assess the performances of the solar kits for maintaining the *Nodes*' continuous operation in two locations. For testing purposes, the first is in Salt Lake City, Utah, and the second is in Farnsworth, Texas, to analyze the performance in a theoretical deployment at a carbon sequestration site.

II. Equipment

a. Sensor Nodes

There are two variants of the *Node*: the *Arduino Version* and the *XBee Version*. The daily power consumptions of both variants are 4.90 W/day and 4.04 W/day, respectively[1]. However, this assessment uses power requirements of 5.0 W/day and 4.1 W/day to ensure adequate energy for the Nodes.

b. Solar Panel and Battery

The company Voltaic sells solar panels and batteries specifically designed for Arduino boards. The batteries have an Always-On feature where the battery constantly provides power to any connected device. If the battery runs out of energy, it automatically continues powering the device after storing enough power. This evaluation uses Voltaic's V25 USB Battery Pack[2] with a rated capacity of 23 Wh. In addition, the associated panel is Voltaic's 2 Watt 6 Volt Solar Panel[3] with a rated peak power of 2.2 W.

Figure 1. Voltaic Battery Pack[2] and Solar Panel[3].

c. Photovoltaic Geographical Information System

The European Commission provides a free interactive tool called the Photovoltaic Geographical Information System (PVGIS) that calculates the performance of solar power systems based on the geographical location[4]. Information given by the website includes 1) power production estimate, 2) battery performance, and 3) probability of the battery charge state at the end of the day.

The model for PVGIS assumes a constant 33% loss of energy due to charging, discharging, lifetime degradation, and dust on panels. Although the *Nodes* require a certain amount of power per day, the solar panels must produce more energy to account for the 33% losses and weather conditions.

III. Calculations

a. Inputs

Calculations for off-grid PV systems require various inputs. The following is a list of inputs and their associated descriptions and values used for this evaluation:

- Solar radiation database:
  - information of solar irradiation based on geographical location
  - PVGIS-NSRDB
- Installed peak PV power:
  - rated peak power of the solar panel
  - 2.2 W
- Battery capacity:
  - rated storage size
  - 23 Wh
- Discharge cutoff limit:
  - charge percentage that the battery can not fall below
  - 20%
- Slope:
  - the angle of the panel relative to the horizontal plane
  - default 35°
- Azimuth:
  - the angle of the panel relative to the direction due South
  - default 0°

The remaining inputs are location and consumption per day. The two locations analyzed by this evaluation are Salt Lake City, Utah, and Farnsworth, Texas; the associated coordinates are (40.765, -111.846), and (36.321, -100.966). The daily consumptions are 5.0 W and 4.1 W for the *Arduino Version* and the *XBee Version* of the *Sensor Nodes*.

b. Calculations

Four different trials are performed on the PVGIS tool using the inputs above to evaluate the performances of each *Sensor Node* at each location. Below is a list of each trial:

1. *Arduino Version* at Salt Lake City, Utah
2. *XBee Version* at Salt Lake City, Utah
3. *Arduino Version* at Farnsworth, Texas
4. *XBee Version* at Farnsworth, Texas

c. Results

The PVGIS tool produces three distinct bar graphs that provide valuable information regarding the performances of the solar panel and battery in powering the *Sensor Node*. The first graph is the PV energy output, which displays the panel's predicted monthly power production and the predicted unstored energy due to a full battery. Next is the battery performance graph displaying the percentages of days per month where the battery is either full or empty. Lastly, the charge state frequency graph shows the probability of the battery charge at the end of a day. Each trial has these three bar graphs displayed in Figures 2, 3, 4, and 5.

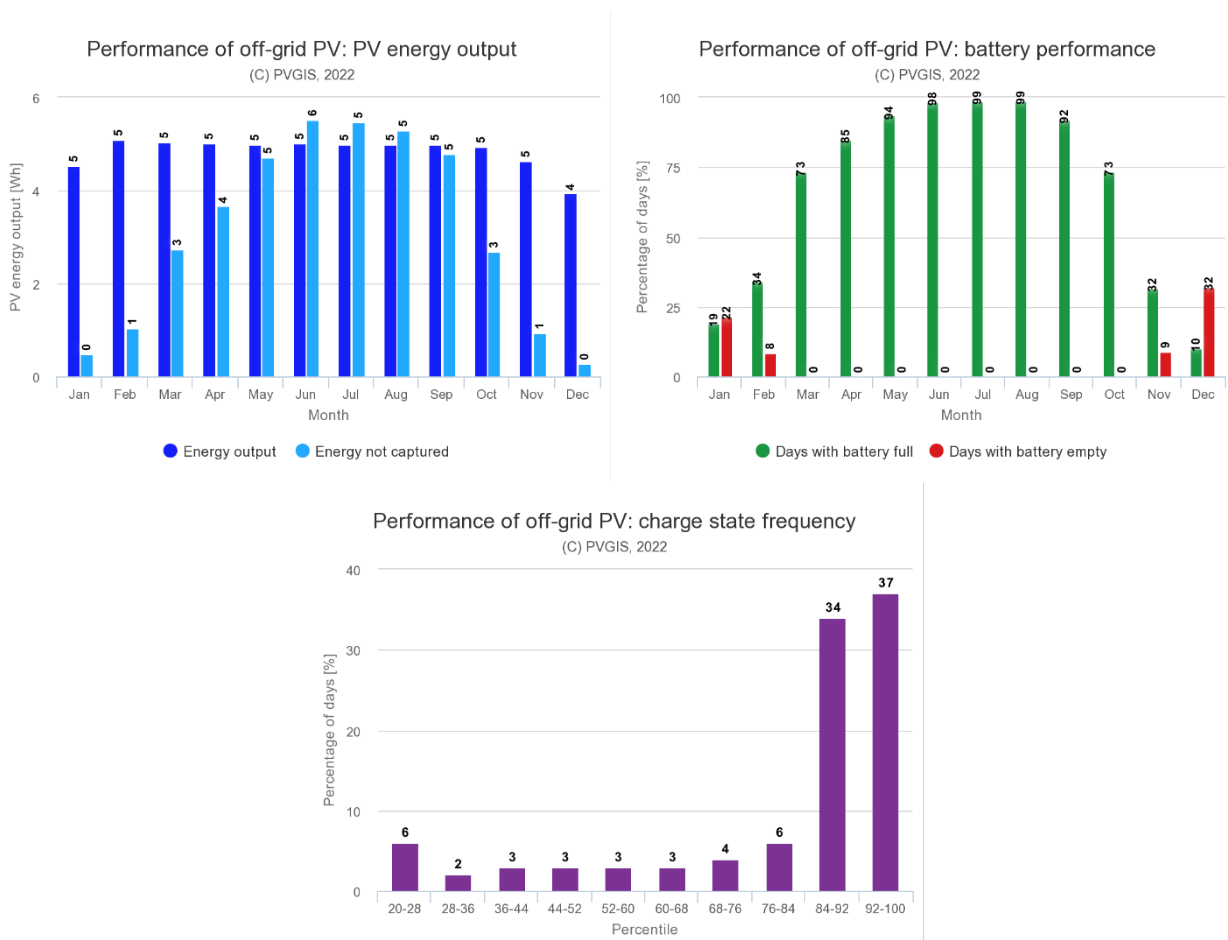

Figure 2. PVGIS Results for Arduino Version at Salt Lake City, Utah.

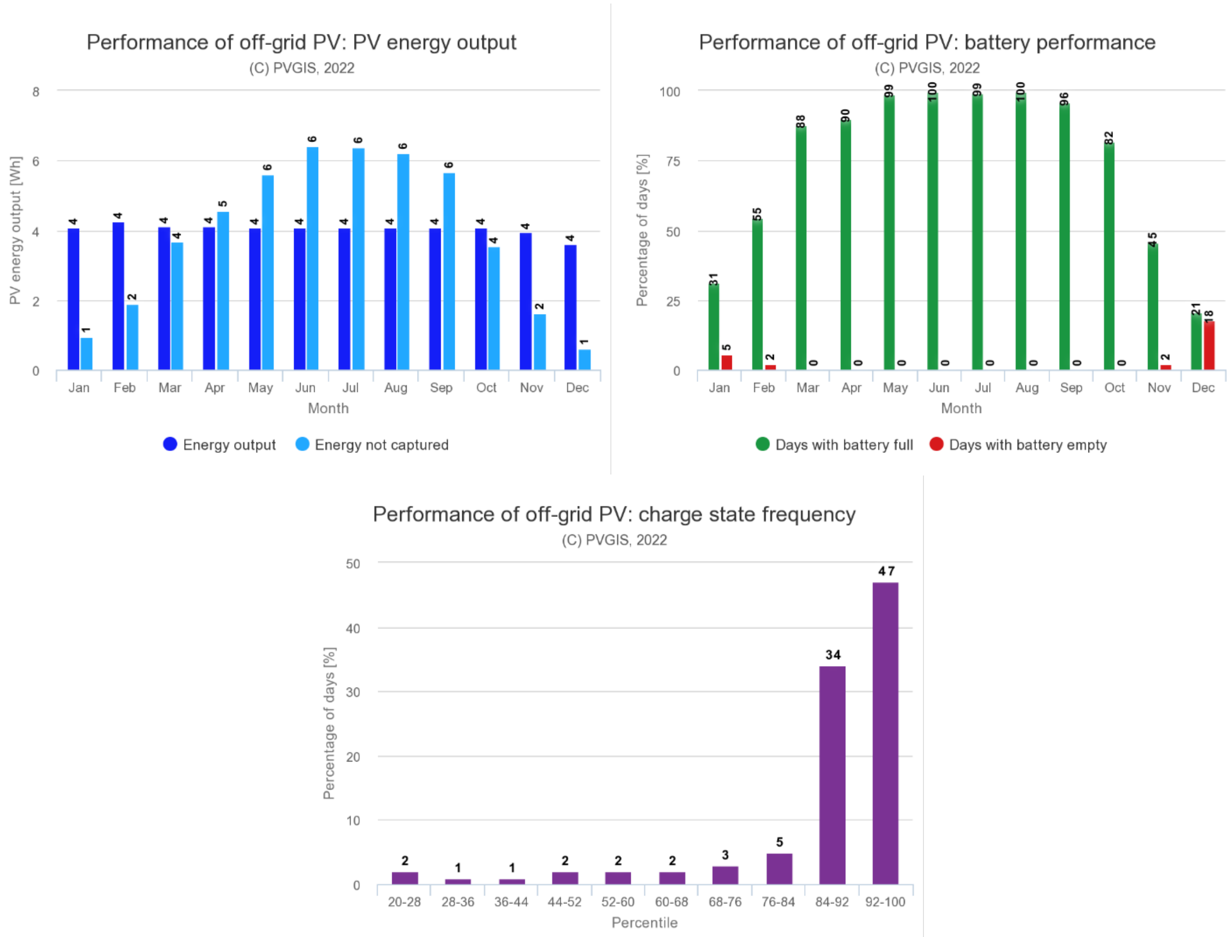

Figure 3. PVGIS Results for XBee Version at Salt Lake City, Utah.

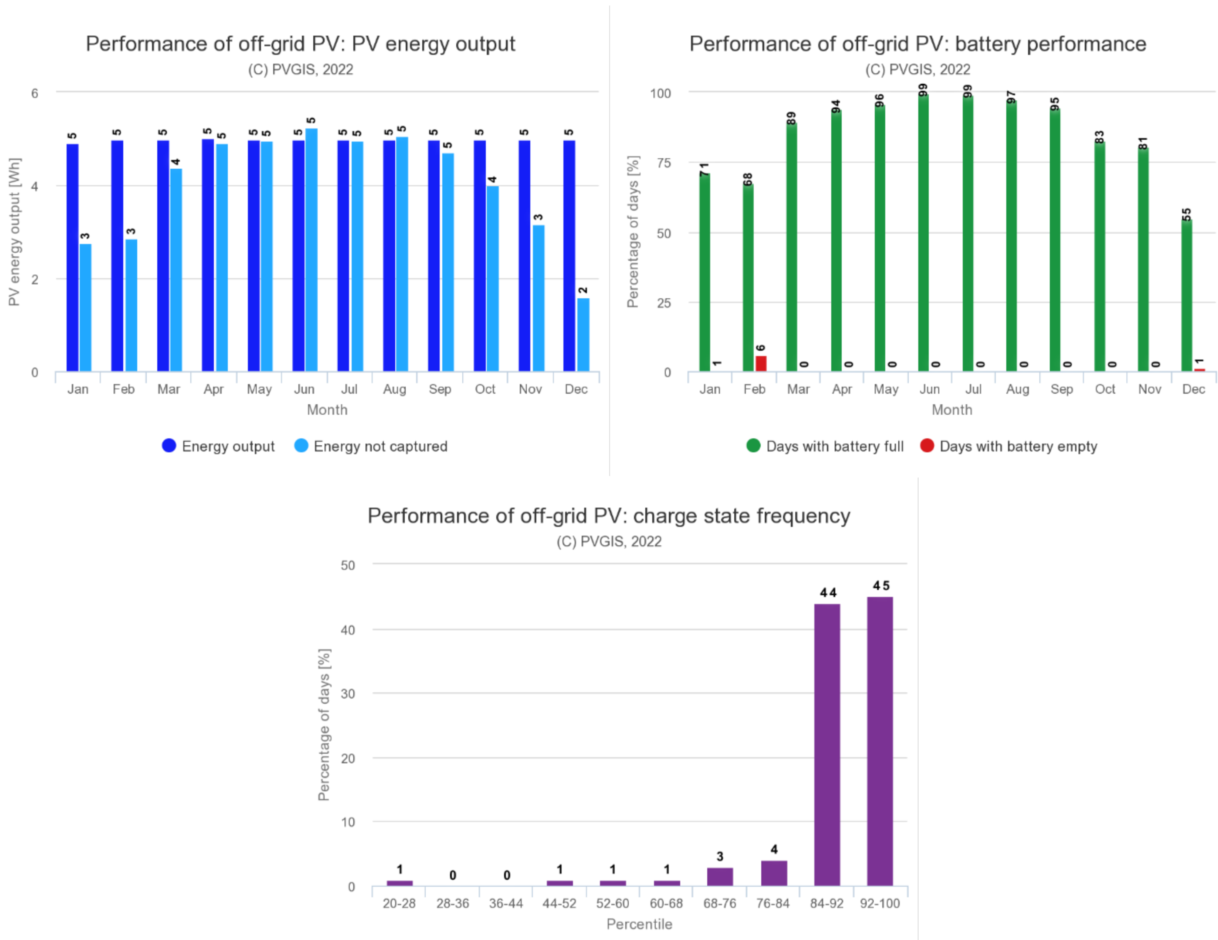

Figure 4. PVGIS Results for Arduino Version at Farnsworth, Texas.

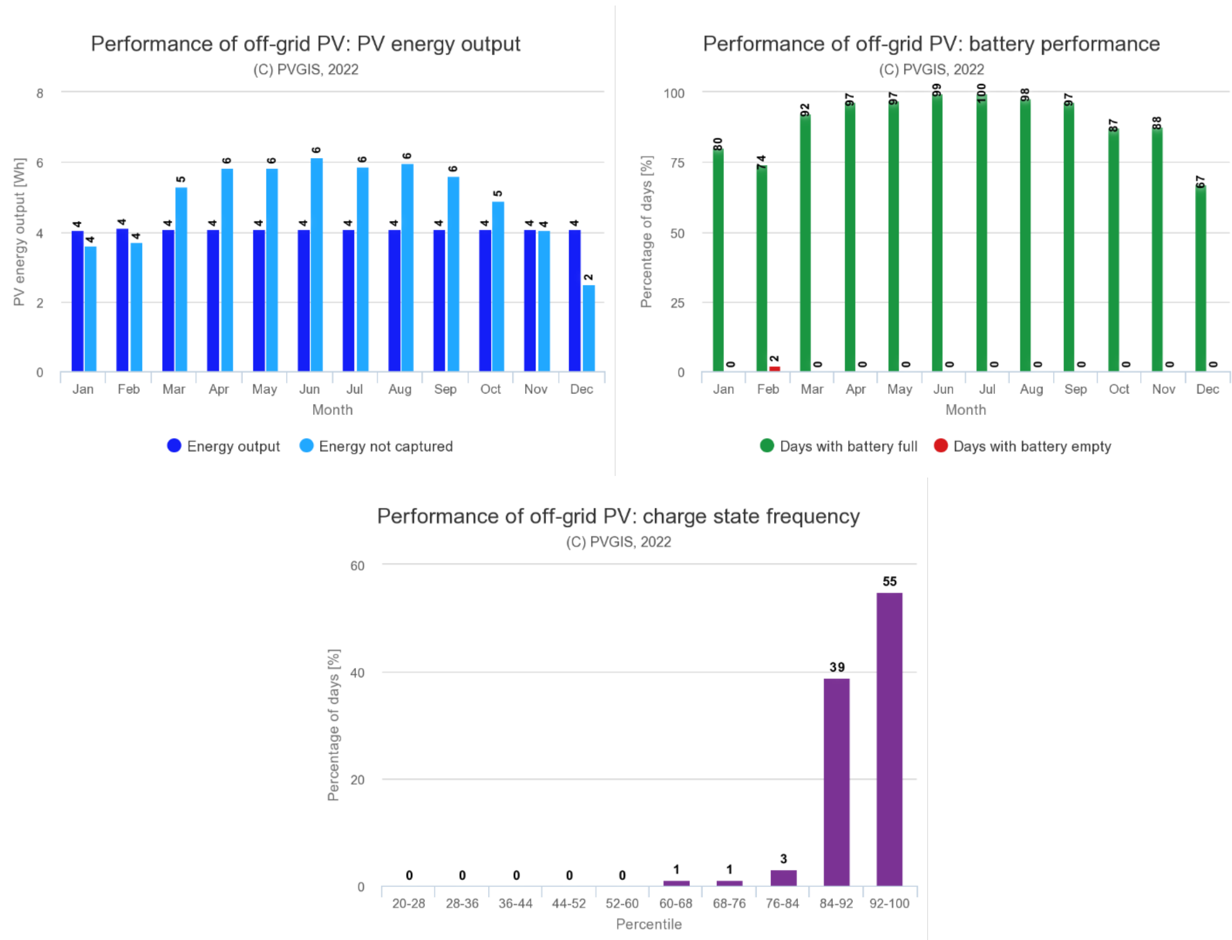

Figure 5. PVGIS Results for XBee Version at Farnsworth, Texas.

d. Analysis

Using the results from the PVGIS tool reveals valuable information about the theoretical performances of the *Sensor Nodes* when solely relying on solar power. Below is a brief analysis and commentary of each trial:

1. Arduino Version at Salt Lake City, Utah (Figure 2)

PVGIS predicts that the PV system produces adequate energy during the spring, summer, and fall seasons. The PV system produces the required 5 W of power to keep the *Arduino Version* operating continuously in these seasons. In addition, 50% of the days in this period yield a battery at total capacity. However, the winter season has days when the battery is completely drained, thereby shutting down the *Sensor Node*. Therefore, a solar panel with a higher production rating must be used to reduce the number of winter days with an empty battery.

2. XBee Version at Salt Lake City, Utah (Figure 3)

The PVGIS prediction for the *XBee Version* is similar to the prediction for the *Arduino Version*. All seasons, except winter, output adequate power to keep the *Node* operational. There are still winter days with empty batteries; however, the percentages of these days are lower than they were for the *Arduino Version* due to the lower power consumption of the *XBee Node*. Like the *Arduino Version*, the *XBee Node* requires a larger solar panel to reduce the percentage of winter days with zero battery capacity.

3. Arduino Version at Farnsworth, Texas (Figure 4)

The carbon sequestration site at Farnsworth, Texas, receives more solar irradiation than Salt Lake City. Figure 4 reflects this by predicting that there are high percentages of days with full batteries across all months. Unlike the results in Salt Lake City, there is a significantly lower percentage of winter days with empty batteries. Therefore, the combination of Voltaic's 2 Watt solar panel and V25 battery is reliable for operating the *Arduino Version* continuously. There are some days where the *Node* shuts down because of an empty battery, but it is infrequent.

4. XBee Version at Farnsworth, Texas (Figure 5)

The *XBee Version*'s lower power consumption has the advantage of having the fewest percentage of days with an empty battery. For example, PVGIS predicts just a couple of days in February when the battery is empty. However, the rest of the days in the year yields adequate energy to keep the *Sensor Node* operational. Voltaic's 2 Watt panel and V25 battery are also reliable for this application.

Table 1 displays a condensed comparison of the battery performance graphs of each trial for the winter months. This table reveals the contrast between the two locations and the contrast between the two *Sensor Node*'s differing power consumption.

Table 1. Percentage of Days during Winter with an Empty Battery.

Trial	Nov	Dec	Jan	Feb
1	9%	32%	22%	8%
2	2%	18%	5%	2%
3	0%	1%	1%	6%
4	0%	0%	0%	2%

IV. Conclusion

This evaluation sought to assess the performance of a solar panel and battery pack in powering two versions of the *Sensor Node* continuously. The PVGIS tool predicted that enough energy is produced during the spring, summer, and winter seasons to power the *Sensor Nodes* continuously. However, both *Sensor Nodes* need a larger solar panel if they are deployed in Salt Lake City, Utah, to provide more power during the winter season. But, if they are deployed in the carbon sequestration site at Farnsworth, Texas, then the 2 W panel used in this assessment is suitable for the *Sensor Nodes*.

Additional resources are contained in the Wireless Sensor Network repository[5] and the CSR Arduino Collection repository[6].

References and Useful Links

[1] Power Usage of the Sensor Nodes
https://github.com/RiceAllDay22/WirelessSensorNetwork/blob/master/Section1-Prototyping/Evaluation-PowerUsage/Document-EvaluationPowerUsage.pdf

[2] Voltaic Battery Pack
https://voltaicsystems.com/v25/

[3] Voltaic Solar Panel
https://voltaicsystems.com/2-watt-panel/

[4] Photovoltaic Analysis Tool
https://re.jrc.ec.europa.eu/pvg_tools/en/

[5] Wireless Sensor Network Repository
https://github.com/RiceAllDay22/WirelessSensorNetwork

[6] CSR Arduino Collection Repository
https://github.com/RiceAllDay22/CSR_Arduino_Collection

Contact
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