Impact of Ammonia (NH_3) on the Energy Production in Photovoltaic Panels

Original Scientific Paper

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Abstract *– The increase in energy demand, the fossil energy crisis, and the trend towards using renewable energies from sources such as the sun or wind have led to the rise in photovoltaic installations. Some of these installations are being installed on farms. While it is true that irradiation levels, location, and inclination of the panels are considered, the influence of certain gases such as ammonia (NH_3), which is present in poultry, pig and dairy farms, is not considered. The present study is carried out in a poultry farm, through the implementation of two data acquisition devices that will be located in two scenarios, the first one exposed to NH_3 levels and the other one free of the influence of this gas, the prototypes are equipped with a 100W panel to measure the power generated and determine if there is a difference in the energy production produced by the influence of ammonia. Data was obtained for ten consecutive days, in which it was determined that the power generated by the panel decreased in the scenario with ammonia compared to the prototype without of influence of this gas, proving that NH_3 influences the decrease in power generated in the solar photovoltaic panel, obtaining average losses of 5%. It is concluded that ammonia (NH_3) influences the efficiency of energy conversion in photovoltaic solar panels.*

Keywords: *Photovoltaic Panels, Ammonia Exposure, Energy Conversion Efficiency, Environmental Impact, Solar Energy*

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1. INTRODUCTION

The use of solar energy has increased in recent years due to its multiple benefits and applications. Photovoltaic solar energy is not only used to provide electricity to areas where access to conventional electricity is challenging and to reduce the carbon footprint, but it also serves as an energy matrix to reduce dependence on electricity generated from other sources [1].

As the adoption of photovoltaic systems grows, it is also essential to understand the factors that influence the efficiency of solar panels. While tilt and orientation are inherent to the design, other factors can reduce the efficiency or performance of the panels, such as dust, shadows, bird droppings, raindrops, and environmental pollution, among others.

The study [2] proposes that the efficiency of a photovoltaic system is reduced due to the accumulation of dust on the surface of solar panels. The power supplied by a solar panel depends on the level of irradiation reaching its solar cells, which can be affected by light shadows caused by atmospheric pollution. In more severe cases, efficiency is impacted by hard shadows formed by the accumulation of dust particles, which interfere with the absorption of solar radiation by the photovoltaic panel.

According to [3], dust can affect power generation systems composed of photovoltaic panels as it accumulates on their surface and remains suspended in the air, preventing the panels from receiving direct solar radiation [4]. When the amount of radiation reaching the solar cells of a photovoltaic panel decreases, power loss occurs.

Addressing issues related to contamination on the surface of photovoltaic panels and how this factor reduces their energy production efficiency is carried out in the study [5]. They consider the increase in temperature of solar panels, which not only decreases the amount of energy generated but also leads to efficiency losses. They conclude that the accumulation of dirt and other contaminants leads to a decrease in power output and an increase in the operating temperature of the panel [6].

Another study was conducted on four factors affecting the efficiency of photovoltaic panels, addressing elements such as dust, water droplets, bird droppings, and partial shading [7]. These factors are analyzed both separately and together. Although air quality is initially considered in determining panel efficiency, the study focuses on performance reduction due to dust accumulation, without considering other elements of environmental pollution resulting from the use of fossil fuels and industrial waste. The study showed the levels of impact of the aforementioned factors and how each of them reduces the efficiency of photovoltaic panels by a certain percentage. However, it does not consider any type of pollutant gases.

Dust accumulation combined with other external factors is the main cause of decreased energy efficiency in photovoltaic solar panels [8]. Cement dust often compacts upon contact with water, forming a layer that completely blocks the photovoltaic solar panel from utilizing solar radiation, even when radiation levels are ideal for energy production. Therefore, dust accumulation, along with factors such as climate, the location of the photovoltaic system, the type of dust, and other parameters, contributes to the reduction in the performance or efficiency of the solar panel or photovoltaic array.

Other studies also showed that the contamination on the photovoltaic panel's surface reduces the amount of radiation received and simultaneously increases the surface temperature, leading to a decrease in energy production efficiency [9]. Depending on the level and type of contamination, the panel's performance varies. In the study, it is determined that, in addition to solar radiation and temperature, other factors reduce the performance of a photovoltaic panel, including dust, dispersed air molecules, water vapor, and other air pollutants. These elements can cause a refraction effect on sunlight, preventing the panel from receiving direct solar radiation, thereby decreasing solar irradiance on the photovoltaic panel [10]. The same study mentions that these conditions worsen when air pollutants, suspended particles, and air humidity are present, as these factors significantly contribute to the decrease in the performance or energy conversion efficiency of photovoltaic panels.

Dust is considered the primary cause of the reduction in energy captured by solar panels, resulting in a significant decrease in their energy efficiency [11]. This is partly due to suspended particles in the air preventing the solar panel cells from directly receiving solar energy. Additionally, the study demonstrates the presence of industrial dust resulting from the accumulation of environmental pollutants and fertilizers [12]. The study [13] determines that the formation of dirt on the exterior of the panel significantly reduces the electricity generated by the panels and also increases their degradation. It is estimated that there are losses between 5% and 30% in a solar generation system annually due to dirt. In the same context, [14] concludes that, in addition to the impact of temperature and wind—meteorological variables that can affect panel performance—the accumulation of dust and other factors, such as rain, lead to the formation of mud or dirt, resulting in a decrease in panel efficiency by 3.95% and 4.03%. Concludes that dust accumulation in a short period can cause a reduction of up to 6.5%, leading to a decrease in voltage and output power [15]. This is due to periodic dust accumulation. Panels exposed to dirt caused by dust tend to reduce efficiency by up to 50% [16].

Stated that when panels are exposed to the outdoors, they are susceptible to environmental factors such as dust, bird droppings, temperature, precipitation, wind speed, among others, which can vary the energy efficiency of photovoltaic panels [17]. It is indicated that the decrease in efficiency can reach up to 30% per hour. Additionally, it was discovered that humidity levels with relative values of 76% and 86% reduce the power and output efficiency of the system [18].

It was demonstrated through experimentation that the photovoltaic efficiency of the panel tends to decrease gradually as the temperature increases, even though the solar radiation level also rises [19]. This means that even with optimal solar radiation, if the temperature increases, the efficiency of the solar panel tends to decrease. Indicates that temperature and radiation directly influence the panel's efficiency, with current, voltage, and output power decreasing as temperature increases[20]. The output power of a photovoltaic panel tends to decrease by 60% to 70% when temperature and humidity combine with dust [21].

All the research and scientific articles reviewed focus on the decrease in energy efficiency and performance in photovoltaic panels due to factors such as temperature, dust, dirt, shading, and bird droppings, among others. However, not much importance is given to gases like ammonia. This study will examine the presence of ammonia effects on photovoltaic generation systems. Due to the lack of research, it is necessary to determine the level of impact, especially since there are many poultry and livestock areas, as well as industries with significant potential for solar energy utilization in their locations. However, due to the insufficient information regarding the direct or indirect problems that ammonia may cause, there is no guarantee or certainty that the implementation of these renewable energy generation systems will not be affected.

2. METHODOLOGY

The methodology is based on the comparative analysis of variables such as irradiation, temperature, and NH_3 to determine whether there are alterations in the voltage, current, and power measurements of the installed prototypes.

For the acquisition and storage of data, a system based on Arduino, humidity sensors, and temperature sensors is used. The measurement of NH_3 levels and irradiation was conducted independently using separate devices. For ammonia levels, the MQ-137 sensor, an LCD display, and an Arduino UNO board were employed. For measuring irradiation levels, a data acquisition device for solar irradiance was used.

The stage of obtaining and storing data can be visualized in the graph of Fig. 1. For the processing of data from voltage, current, solar irradiation, temperature and NH_3 level sensors provided by each of the prototypes located in areas with and without influence of the NH_3, these values are obtained by a data acquisition system based on Arduino and then stored in SD memory device, to finally process the collected information using processing package such as Python.

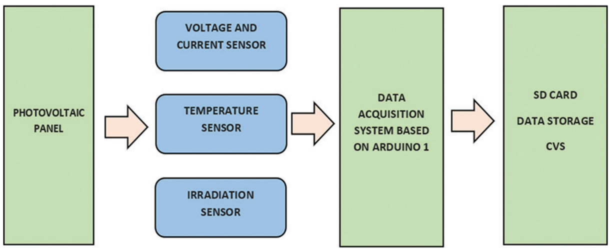


Fig. 1. Information Processing

2.1. OBTAINING AND SAVING DATA FROM THE PHOTOVOLTAIC SYSTEM.

The first stage of the project consists of obtaining experimental data in the two proposed scenarios. The data from the photovoltaic system will be subsequently analyzed using the methodology developed to determine the possible differences in the two study scenarios. This stage consists of the following processes:

Measurement of variables: By placing sensors at specific points on each of the prototypes, values of relative humidity, ammonia (NH_3), panel voltage, and panel current are obtained, and irradiance measurement is carried out separately.

Data acquisition and storage: Data acquisition is performed by means of an Arduino Uno board that processes the analog signals coming from each of the sensors and stores them on an SD card for later analysis.

2.2. PROTOTYPE OF THE DATA ACQUISITION SYSTEM.

The experimental methodology was applied in two scenarios, exposed to high levels of NH_3 and another without NH_3, at the poultry farm "El Belén," located in Pillaro-Ecuador.

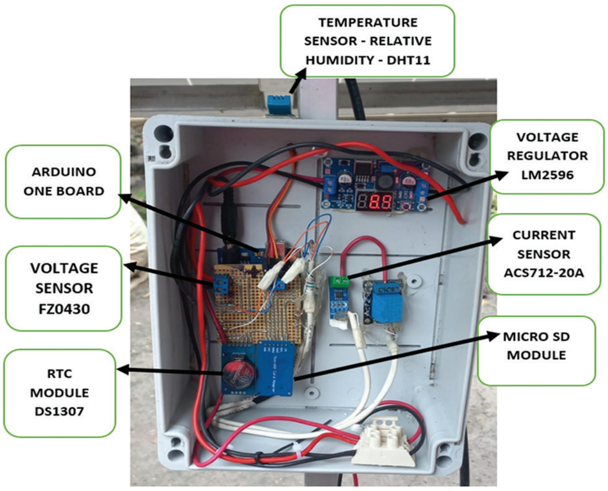


Fig. 2. Data Acquisition System Components

The data acquisition system has temperature, voltage and current sensors that allow us to measure variables such as the voltage and current consumption, in addition to the ambient temperature in the photovoltaic panel, each of the sensors send the information to an Arduino Uno card to convert the analog signals from the sensors to be subsequently analyzed in the micro-SD module. An RTC (real-time clock) module is available to take voltage, current, and temperature measurements.

These will later be analyzed with the NH_3 measurement systems and a solar irradiation measurement device to determine the differences of the mentioned variables in each analyzed scenario.

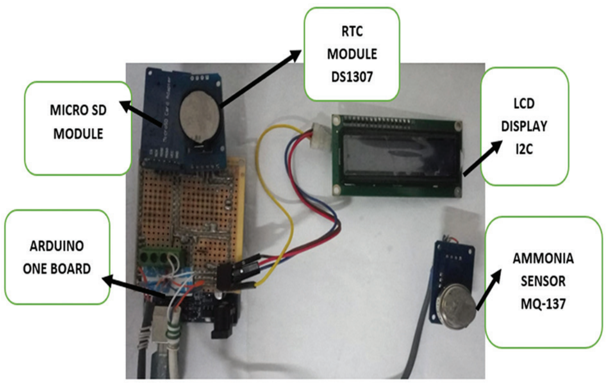


Fig. 3. Ammonia Measurement System

The ammonia NH_3 meter during the pre-stage of data acquisition allows us to determine where the highest NH_3 concentration scenarios exist. In this way, it was determined that shed #6 presents considerable and constant levels of the mentioned gas. It should be emphasized that although there were scenarios in which measurements between 5-15 ppm (parts per million) were obtained, they were not constant due to the air currents used for the ventilation of these sheds.

Using the same operating principle, the ammonia sensor was modified to store gas level readings, which are synchronized with the readings and measurements from the previous device (voltage, current, temperature). This was achieved by adding the RTC module and the Micro SD module for data storage. The collected data was later analyzed using tools such as Excel, considering that each data acquisition device generates a CSV file (comma-separated values). These files will be merged for joint analysis and used to create graphs with the Python tool in order to carry out a comparative analysis based on the generated graphs.

The system used to analyze the power generated in both scenarios consists of the following components:

100 W Photovoltaic Panel with an open-circuit voltage (Voc) of 22.28 VDC and a short-circuit current (Isc) of 6.05 A.

Fig. 4. Experimental Prototype

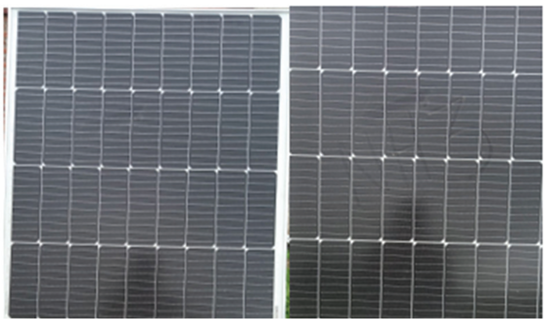


Fig. 5. Panel cleaned (left) and panel without cleaning (right)

2.3. RESULTS VISUALIZATION.

During the first stage, display elements are available to visualize values of voltage generated by the panel and percentage of ammonia in parts per million (ppm), where a voltmeter and LCD display are available to visualize the percentage of ammonia, respectively.

2.4. PHOTOVOLTAIC SYSTEM TEST PROTOTYPE.

The data acquisition prototype was tested in stages. In the first stage, measurements were made of the panels in Voc to determine through the measurements whether the solar panels generate the same amount of open-circuit voltage.

Subsequently, NH_3 levels were measured in several scenarios to determine where there was a permanent concentration of the gas and whether it was not affected by airflow or forced ventilation systems.

Fig. 6. Prototype under the influence of NH_3

Prototype 1 was located near the source of ammonia. After the measurement to determine in which area or shed there was a higher concentration of this gas, it should be noted that it was chosen considering the concentration and constant levels for experimentation and comparison for the case study.

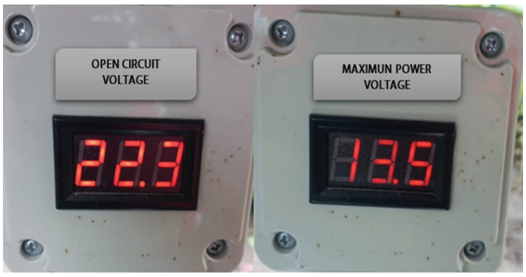
Fig. 7. Prototype free of NH_3 exposure

Prototype 2 was implemented away from the influence of ammonia to obtain current and voltage values, allowing for the calculation of the power generated. Then, a comparative analysis was performed to determine the decrease in power due to exposure to NH_3 in prototype 1.

Finally, the prototypes are placed in the area of influence of the mentioned gas to start data acquisition. Once corrected and the necessary modifications have been made, a period of continuous data acquisition begins for 10 days (07-02-2025 to 16-02-2025) during which data on variables such as temperature, power generated, and irradiation are obtained.

3. RESULTS

During the first testing phase, a voltmeter was implemented to determine whether the system had a voltage signal, that is, whether it was operational.



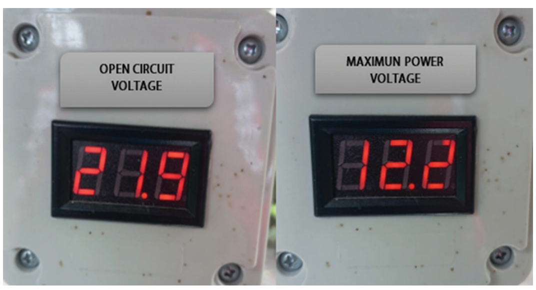
(a) (b)

Fig. 8. Voltage in the scenario without NH_3. (a) Open circuit and (b) with load

In the scenario without exposure to ammonia, a slightly higher open-circuit voltage was measured compared to the voltage recorded in the scenario with NH_3 exposure. It is important to note that initial measurements were taken under open-circuit conditions, that is, without any load connected to the photovoltaic panel.

Subsequently, measurements were repeated with a load connected. The data acquisition was carried out in a synchronized manner under identical irradiation levels, in order to determine whether the presence of ammonia had any effect on the energy conversion process. As observed, there is a voltage drop of 8.8 volts when the load is connected.

In subsequent measurements, the results obtained from the three implemented data acquisition devices were compared to correlate temperature levels (°C), ammonia concentration levels (ppm), and, based on voltage and current readings, determine the power generated by the photovoltaic panel. This data was then used to perform a comparative analysis of the results obtained from the prototype exposed to NH_3 levels.



(a) (b)

Fig. 9. Voltage in the scenario with NH_3. (a) Open circuit and (b) with load

In the scenario exposed to NH_3 levels, measurements of variables such as temperature, voltage, and current were considered under the same solar irradiation conditions as in the ammonia-free scenario. However, an increase in temperature of 1.5°C was observed compared to the 12°C recorded in the unexposed scenario. This suggests that the panel's voltage generation efficiency also decreases with temperature.

As in the previous case, open-circuit voltage measurements were first conducted to assess whether the temperature increase had any effect on the voltage without a connected load. Subsequently, a load was connected to measure the operating voltage. A drop of 0.4 volts was recorded under open-circuit conditions, and a 1.3-volt drop was observed under load conditions.

After analyzing the various parameters used to determine the impact of ammonia on photovoltaic generation systems, the correlation between NH_3 concentration levels and temperature, as well as the relationship between temperature and generated power, is considered significant. The generated power is calculated by multiplying the voltage and current values obtained from each prototype.

This study is based on experimentation using a data acquisition system to compare two scenarios under the influence of ammonia (NH_3). The project focuses on data acquisition from two scenarios: in Scenario 1, the system is exposed to average ammonia levels ranging from 3 to 5 ppm, while in Scenario 2, the prototype is either free from exposure or situated in an environment with low NH_3 levels. The objective is to determine whether the mentioned gas influences energy conversion efficiency.

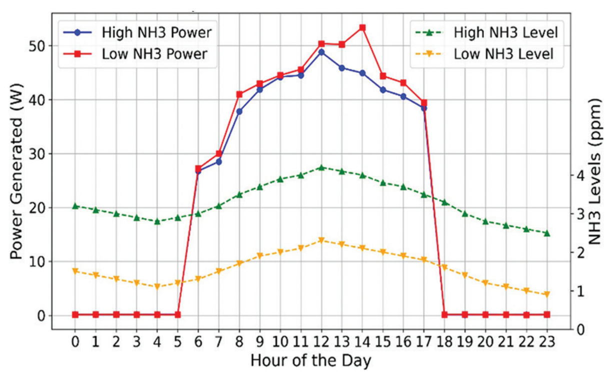


Fig.10. Generated Power vs. NH_3 Levels

According to the results, more power is generated in the scenario without exposure to NH_3, while in the scenario with exposure, there is a slight decrease in the power produced, this decrease is inversely proportional of concerning the levels of ammonia, i.e., if there is a higher concentration of ammonia level, the power produced by the solar panels is lesser.

Based on the values obtained, it is possible to determine the relationship between the power generated and the high and low NH_3 levels as shown in Fig. 6, which, in the first instance, can be attributed to the fact that NH_3 influences the amount of power generated by the solar panels.

In a subsequent analysis, it was determined that ammonia levels are directly proportional to the measured temperature levels; therefore, due to the chemical properties of ammonia, which absorbs heat, the ambient temperature surrounding the ammonia source increases. Therefore, as the temperature of the area where the panel is located increases, the efficiency of the panel decreases as a result of the temperature increase.

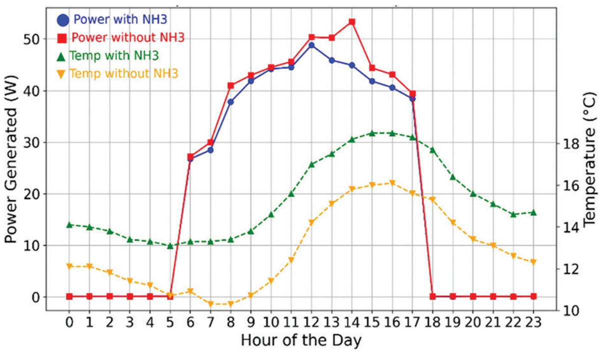


Fig. 11. Comparison of Generated Power and Temperature with and without NH_3

Fig. 11 shows the decrease in power due to the increase in temperature caused by the ammonia levels, with a minimum decrease of 2-3% of the power generated concerning the panel free of exposure with low exposure levels, with an average decrease of 5.5% and under certain conditions, a maximum decrease of 10% is reached.

The analysis of variables such as temperature, solar irradiation, voltage, current, and power enables a comparative evaluation of the measured data to determine whether there is a variation in the generated power as a function of certain variables affected by the presence of NH_3.

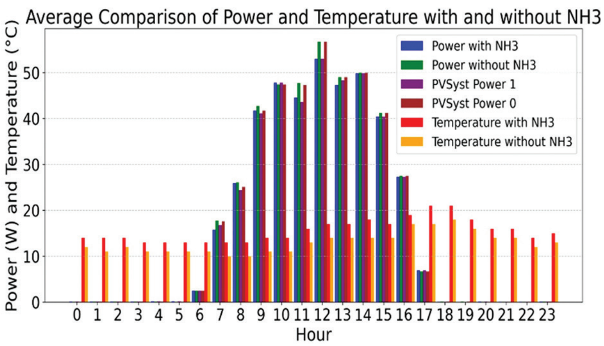


Fig. 12. Comparison of Generated Power and Temperature with and without NH_3. Measured and simulated

Fig. 12 shows a negative impact of NH_3 on the energy conversion efficiency of the photovoltaic panel. Comparing the "Power with NH_3" and "Power without NH_3" bars, it can be observed that, during peak solar irradiation hours (approximately 10:00 a.m. to 2:00 p.m.), the power generated without ammonia is higher than that generated with ammonia. This same trend is reflected in the data simulated using the PVSyst software. Examining the "PVSyst Power 0" (with NH_3) and "PVSyst Power 1" (without NH_3) bars, it is confirmed that the simulation model also predicts a power reduction when the presence of ammonia, represented by the increase in temperature, is considered.

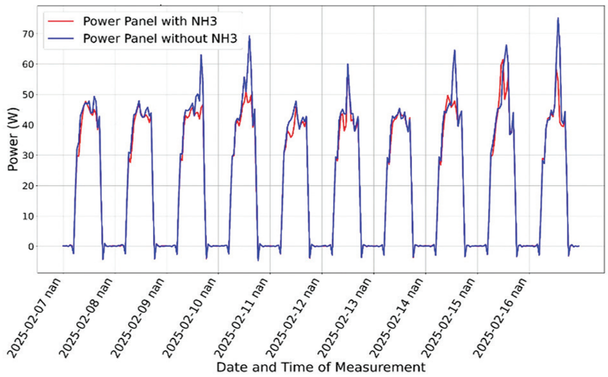


Fig. 13. Generated Power with and without NH_3

Fig. 13 shows the power generated by the panel exposed to ammonia and compared with the power produced by the prototype free of exposure, for a consecutive period of ten days, in which it can be verified that the power generated by the panel free of exposure to ammonia is slightly higher than the power generated in the photovoltaic panel exposed to levels between 3-5 parts per million (ppm) of NH_3.

Table 1. Analysis of results obtained

Day	Average Power, With NH_3(W)	Average Power, Without NH_3(W)	% Loss Power (W)
1	40.44	42.38	4.81
2	39.45	40.84	3.51
3	40.52	44.30	9.32
4	41.43	45.65	10.20
5	37.79	39.78	5.25
6	40.51	41.44	2.29
7	38.69	39.28	1.51
8	40.99	43.66	6.49
9	43.30	44.90	3.68
10	41.14	44.60	8.41
% Total Power Loss (W)			**55.52**
% Average Power Loss per day (W)			**5.55**

Based on the results obtained and their subsequent analysis, Table 1 shows the percentage loss of power generated under the influence of ammonia compared to the power produced by the panel free of exposure, determining that there is an average power loss of 5.5%, a maximum loss of 10.20% and a minimum loss of 1.51%. Although other factors may affect the performance or decrease the energy conversion efficiency, it is considered that the two prototypes are exposed to the same amount of solar irradiation. Through consecutive measurements taken over a 10-day period, a comparative analysis was carried out on the main variables involved in the energy conversion process, including solar irradiance, temperature, and power output. Based on this analysis, it was determined that power decreases as temperature increases (NH_3 increases).

Although other parameters, such as dust and dirt, can affect system performance, the photovoltaic panels were properly cleaned to eliminate these factors from influencing the energy conversion process. Additionally, both prototypes were installed under identical conditions in terms of location and tilt angle to ensure that no external variables would introduce inconsistencies or errors in the research results.

4. CONCLUSIONS.

The study confirms that NH_3 exposure negatively impacts the performance of photovoltaic panels. The observed efficiency losses suggest that NH_3 contamination should be considered in PV system design and maintenance, particularly in regions with significant ammonia emissions. Further research is recommended to explore mitigation strategies and protective coatings to minimize NH_3-induced efficiency degradation. Additionally, long-term studies are needed to assess the cumulative effects of NH_3 exposure over extended periods.

The implementation of data acquisition systems enables the analysis of comparative data to determine factors that influence or affect certain variables that may impact a process or phenomenon. In this case, it determines the influence of ammonia on the energy conversion efficiency of photovoltaic solar panels.

The results of this research determine the impact of ammonia (NH_3) on the energy conversion efficiency of solar panels by comparing the power generated in each of the proposed scenarios. It was found that the presence of this gas alters the ambient temperature near its source due to its characteristics, causing the temperature to rise. This increase in temperature leads to a decrease in the power generated by the photovoltaic solar panel exposed to significant levels of ammonia.

Based on the results obtained, the experimentation should be replicated on a larger scale to determine the level or degree of impact on the efficiency of a photovoltaic system. Additionally, a cloud-based data storage system should be implemented to create a database of the measured parameters for projects related to machine learning and data science.

Following the experimental tests carried out, it was determined that NH_3, present in bird feces, indirectly affects power generation in solar panels by increasing the temperature levels in the areas surrounding the source of this gas. Therefore, as the temperature rises, there is a slight decrease in the amount of power generated by photovoltaic solar panels.

5. ACKNOWLEDGMENT.

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