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Experimental investigation of bird dropping and soiling influence on Photovoltaic module output power in a humid and dusty environment

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Abstract:

Over the past few decades, the increased use of energy resources has led to increased electricity demand, compounding a constant shortage of nonrenewable energy resources. However, dust accumulation, humidity levels, temperature, and bird droppings can negatively affect the efficiency of PV (Photovoltaic) systems. Bird droppings can cause shading areas and hot spots on PV cells, gradually reducing their performance. This study aims to investigate the impact of bird droppings and soiling on photovoltaic modules by developing an experimental setup. The primary objective of this study is to define a cleaning pattern depicting how much cleaning is required, aiming to stabilize output power from PV panels. An experimental setup comprises two PV panels with monitoring and data logging sensors. During the cleaning process, a clean PV module will be compared with a module affected by bird droppings and soiling. The experiment was conducted for 25 days in a dusty and humid environment, affecting approximately 30% of the PV panel area by bird droppings. As a consequence, the module's output power decreased by 35%. In order to predict when the PV module becomes completely opaque, resulting in zero power, after the experiment has been conducted, multiple linear regression techniques have been applied that show the whole panel will cover up in 82 days with bird droppings having a covering area of 128500 mm^2. The experimental investigation concluded that bird dropping and soiling can significantly impact PV panel output degradation. Regular cleaning patterns will help to ensure efficient operation and maximize electricity generation.

Keywords: *Photovoltaic; Bird dropping; Power degradation; Renewable energy; Experimental investigation*

1. Introduction

The energy crisis problem is of great concern for the world [1], which is dependent upon natural resources that are declining due to the increase in demand and less dependency on renewable energy [2]. Renewable energy sources, the sustainable and green form of

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energy, are now the primary source of attraction for power generation. Besides that, it is the most reliable and abundant energy, ensuring high development in the PV energy sector [3]. Solar radiation allows abundant and free energy harnessing through the simple phenomenon of generating electricity through PV panels, which absorb sunlight and transform it into electrical energy [4]. PV cells are semiconductors that generate electrical power from light, utilizing a p-n junction exposed to the sunlight. These cells employ various manufacturing methods and different types of semiconductors, with silicon PV cells being among the most widely used [5]. Solar photovoltaic cells work by absorption of photons from the sunlight, which excites electrons within the semiconductor material in the panel, resulting in the flow of electricity through the panel.

Moreover, electricity generated by PV panels can also be stored in batteries or used directly from PV panels [6]. PV power production relies on different environmental factors impacting this absorption process, including humidity, dew, wind velocity, and dust accumulation [7]. The growth of bird droppings on the PV module surface can reduce the efficiency due to reduced transmittance [8]. Given their limited sources, different environmentally friendly and effective replacements have been explored to change conventional energy [9]. Significant renewable energy system developments can help reduce carbon emissions globally [10]. The statistical report on renewables shows a 7.4% capacity development, with an additional 176 GW. Notably, 54% of the expansion happened in Asia, mainly with new solar and wind capacities [11]. PV technologies are growing popular, and it is dynamic to take appropriate environmental protections [12]. It is vital to investigate the sustainability level of renewable technologies, assess their environmental influence, and mitigate impacts to prevent any further influences [13]. The government of Pakistan has permitted more projects related to PV technologies capable of producing 2000 MW and aims to reach 10,000 MW in the upcoming years. The power generation in Pakistan is mainly from fossil fuels, 58%; hydropower, 30%; and nuclear and renewable, 10% [14].

In the past two decades, extensive research has been conducted to discover electricity generation using solar energy sources [15]. Many studies have investigated areas such as enhancing solar power efficiency, improving cost effectiveness, and evaluating environmental impacts [16]. Academic researchers have worked to understand PV panel performance and optimize systems for numerous applications. The main objectives were to extend knowledge of solar energy conversion, improve generation efficiency, and reduce operational costs [17]. Solar energy, generated by sunlight, is an alternative to meet high energy demands. Its applications are in numerous sectors, including industrial and residential, offering efficient solutions [18]. During a similar study, it was observed that renewable energy sustainable qualities eliminate long term depletion doubts. Solar energy boasts more significant availability and cost effectiveness than other renewable options for fulfilling future energy requirements [19]. The impact of bird dropping has been investigated in recent studies, which show that the increased buildup of birds caused a 36-38% drop in the power of the PV module compared to the clean module. However, the PV module voltage was barely influenced.

Furthermore, the PV module's output power and efficiency under birds' buildup were found to be decreased by 26% and 43%, respectively, when compared to the clean module [20]. Another research study created an elementary I-V scan to analyze variations in the PV module I-V and P-V characteristic curves. The study utilizes the I-V scanner to examine and analyze partial shade situations that simulate droppings from birds and unevenly distributed soiling deposition on the outer layer of PV modules [21].

Based on the DS-100M solar panel, Xuan mathematically modelled the PV module in Simulink. The power output, current, and voltage of a PV panel decrease as solar irradiation levels decrease from 1000 to 100 W/m^2. A straightforward and precise approach is recommended to model PV arrays that are easily adjustable. A shunt resistance significantly impacted the PV panel's operating characteristics [22]. According to the study, a MATLAB model has been developed to analyze PV cells based on mathematical equations on varying irradiances. To create a system that accurately predicts solar PV cell behaviour in different environmental conditions while extracting physical parameters specific to each solar PV cell [23]. Analyzing equations under STC reduced a five-parameter electrical model of a single diode to two parameters. The research concluded that a complete PV, characteristic model could vary irradiance and temperature based on data obtained from nominal operating cell temperature tests. Different PV modules were tested using the proposed methodology, resulting in accurate estimations [24].

Mohamed, observed that various factors affect the performance of PV modules, such as temperature, humidity, clouds, dust, and rainfall. Further, higher temperatures and sand accumulation on the modules are challenges in desert regions. Shade can be caused by sand particles, foliage debris, and bird droppings that build up over time. As dust accumulates on the array, output power is reduced, which can be remedied by washing it with water. A dirty module might gradually experience lessened output power, which can be quickly recovered after cleaning [25]. Researchers conducted different measurements to understand the impact of dust buildup on PV output. The research concludes that while dust accumulation affects photovoltaic modules in Belgium, Using special coatings on the glass can potentially reduce performance loss due to dust deposition. However, the additional costs of coating these PV modules are not justified [26]. According to a study on shading due to dropping, shading can reduce the power output of PV modules and arrays. To prevent hot spots from developing in partially shadowed PV modules in current commercial products, bypass diodes with reverse polarity are used parallel to a collection of solar cells in serial connection. Due to the small area, bird litter shading hardly affects output characteristics. However, a hotspot will occur because the forward bias voltage is below the diode's threshold, so even a small enough shadow will not activate the bypass diode [27].

Solar irradiance and temperature are strongly correlated with the amount of power harnessed by PV modules. Based on the results of the experiments, dust and bird droppings accumulate on PV module surfaces, resulting in consistently reduced output power. During an exposure period of 11 weeks, the growth density caused by bird droppings makes PV modules' surfaces opaque, reducing solar irradiance. The efficiency of PV modules decreases as more dust accumulates on their surfaces [28]. A study was conducted to determine how soiling-induced shading affects DC voltage and current in PV modules. Smog, for example, causes soft shading by partially blocking sunlight, while solid materials accumulate on modules to cause complex shading. Soft shading reduced the module's output current without affecting the voltage level. Complex shading, however, determines a module's performance, whether one or all cells are shaded [29].

Sisodia assessed the performance of bird droppings. The bird-dropping effect must be considered when analyzing the impact of different tilt angle configuration ratios on energy yield, as the highest yield may only be achieved if this factor is addressed. At the end of winter, power loss significantly decreased in August, while the opposite was observed in March. Throughout the year, these fluctuations in power loss were noticed. Birds demonstrated the effect of plate inclination on PV output through their year-round sitting and walking tendencies [30]. In a study by Mustafa, four factors that influence the performance of PV panels are analyzed simultaneously: water drops, dust accumulation, bird droppings, and shading effects. In addition to cooling the panel's surface, water lowers its temperature. Research studies show that cooling PV panels with water can increase their efficiency. It was found that bird droppings on a PV panel reduced its power output, showing that it can be hard to get the maximum power from a PV setup in cases shaded partially [31].

PV panel output can be reduced due to bird droppings, especially in dry regions, where bird droppings can accumulate, obstructing sunlight access and producing hotspots. This rapidly reduces the PV panel age, resulting in replacement [32]. According to Juhani, dust and bird droppings accumulating on solar panel surfaces are a significant problem, particularly in desert regions. Due to the reduced transmittance of sunlight through the glass cover, sunlight reaches fewer cells as dirt accumulates. Droppings from birds exacerbate this issue by blocking even more sunshine and decreasing energy generation. Even though the buildup of these substances is one of the most critical factors affecting the performance of solar panels, it is also one of the most straightforward problems to resolve. Depending on where the solar panels are located, dusty panels can lose up to 25% of energy, illustrating the importance of maintaining and cleaning the panels to achieve optimal performance. The PV panels installed were monitored daily for voltage, current, temperature, and power output [33]. A bird dropping's tendency to stick to a PV panel's surface due to its moisture content significantly impacted panel efficiency. However, coal dust had the most negligible effect, independent of tilt angle. Due to its quick evaporation and lack of adhesion, coal dust has the most negligible impact on all soil types. It was determined that bird droppings contributed approximately 46.42 % to 89.18% of the efficiency loss, which is a high amount, while coal dust contributed less than 13% [34].

Some latest research has also been conducted to find the influence of soiling on the performance of PV modules. According to Rashid, a study was conducted in two different regions of Pakistan, Bahawalpur and Islamabad. In the Bahawalpur region, the amount of soiling is more than in Islamabad, which reduces the output of the PV panel more than that installed in Islamabad [35]. Okan reported that different types of soil and dust particles impact the output power of the PV module differently [36]. Deepak experimented with five different arrays of PV power plants. Different types of dust have been accumulated on it, including cement, sawdust, coal, dry leaves, and talcum powder. It was revealed that coal and cement dust significantly impact the PV module's output power [37]. An outdoor experimental study was conducted by Kazem to find the impact of soiling on different types of module surfaces. It was concluded that monocrystalline modules attract more dust than polycrystalline [38].

Another research was conducted by Chaudry to gauge the impact of different types of dust and the temperature effect related to dust deposition. It was concluded that tiny particles of dust increase the temperature of the panel surface as compared to large particles [39]. Tarik reported that small particles of soiling reduce the optical transmittance by up to 13%, resulting in a 2% increase in panel surface that can reduce the module output [40]. Bing developed an analytical model to find the influence of soiling on the PV module. It was concluded that the parameters model of the PV panel can predict the panel performance based on data on soiling [41]. Nabil conducted an outdoor experiment to find the impact of soiling with high winds in the deserts. Three different types of modules have been used with different morphologies. It was concluded that monocrystalline modules have been affected most in the desert climate regions[42]. Mingda used a feature-based regression model to find the impact of soiling. Image data shows that small dust particle’s geometrical shapes have the more complex geometrical shape that attracts the panel surface, which increases PV module loss [43]. Anti soil protective material has been developed to coat the PV module. Muhammad reported that anti soiling coating application on the PV modules reduces the dirt and soiling accumulation on the PV modules, ultimately increasing the performance of the PV module [44].

The literature discussed above shows that bird droppings can negatively impact the performance of solar panels. Shading caused by accumulated droppings reduces their efficiency and power output, and regular cleaning is essential to prevent a buildup of bird droppings and maintain optimal energy production. Moreover, these droppings contain corrosive chemicals, including uric acid, ammonia and different salts that can harm the panel surfaces over time, potentially shortening their lifespan. Implementing bird deterrent measures such as physical barriers or visual deterrents can prevent birds from landing on the panels. The literature also depicts a gap in collective impact estimation of soiling and bird dropping that impacts the output PV module.

2. Methodology

Many environmental and ecological factors affect the PV module's output power. The bird dropping and soiling vastly affect the performance of the photovoltaic module, which ultimately decreases the power output. It is crucial to consider environmentally friendly options that preserve the well-being of birds and uphold the local ecosystem. The methodology section is structured as follows: Section 2.1 defines the experimental investigation's site selection process and environmental parameters. Section 2.2 discusses the design of the environmental investigation setup deployed for measuring bird dropping. Section 2.3 defines the data acquisition setup and sensors for real-time data acquisition. Moreover, section 2.4 discusses the scheme used for data analysis acquired from the experimental investigation setup. Figure 1 explains the investigation workflow.

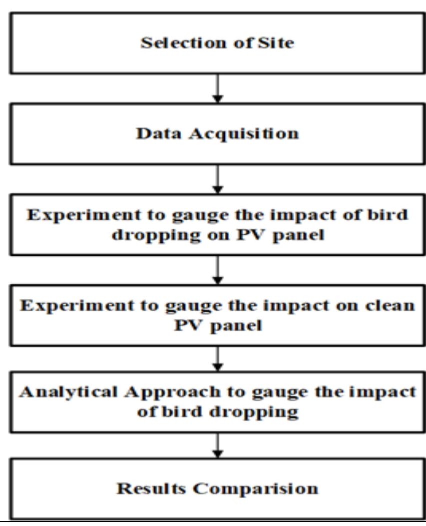

Fig. 1. *Experimental workflow of the investigation.*

2.1. Site Selection

A crucial factor to consider in conducting experimental investigations is selecting the site to conduct the experiments. The study was conducted in Karachi, with latitude and longitude coordinates (24.86, 66.99). The site selected for this investigated study has a hot and humid climate. The experiment was conducted from 10 May 2023 to 04 June 2023.To accomplish our research objective, the presence of birds in the experimental study will be considered a critical factor. It was ultimately decided to select a site near the coast with abundant rock pigeons and other bird species. Figure 2, shows the image of the bird's attraction toward domestic photovoltaic panels.

Fig 2: *Bird's Attraction towards PV Panel*

2.2. Experimental Setup

An indigenous experimental setup has been designed to gauge the impact of bird droppings on the PV panel. The experimental setup is based on the data acquisition devices used to measure the data related to the experiment. The dimensions of the structure were carefully selected as 3x1x5 ft to ensure an appropriate size for the experimental setup. Steel sheets were chosen for robust strength in constructing the physical structure. The CAD model of the experimental setup is depicted in Figure 3. The experimental setup is equipped with a feeding tray and barley grains to attract the birds to sit near the PV panel experimental setup. Similarly, the clean panel has iron spikes to distract birds from sitting on the clean PV panel.

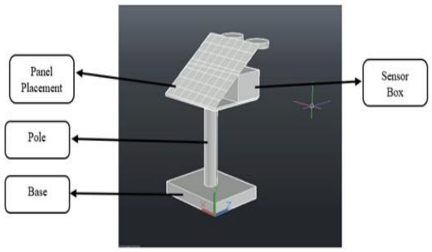

Fig 3: *CAD model for experimental setup*

In the experimental setup, two PV panels are installed on a bench; one is set to be cleaned over a twenty-five-day period, during which the other panel is set to be cleaned as well. In addition to the first PV panel, a second one was installed, and no cleaning was conducted for twenty-five days. Both PV panels are installed at 30° to obtain the maximum irradiance. As a part of the data acquisition system, sensors are installed in the PV panel to collect readings of the parameters that impact the PV panel performance. Figure 4 shows the experimental setup for investigating the impact of bird dropping on PV panels.

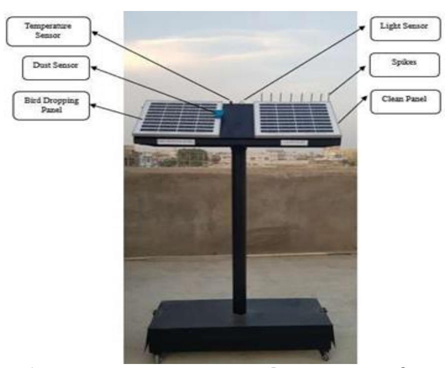

Fig 4: *Experimental setup for investigating bird dropping effect on photovoltaic panel*

2.3. Data Acquisition

Different sensors are used to acquire data on physical parameters affecting PV performance. For real time data collection, a sensor box was developed consisting of necessary sensors, including voltage, current, temperature, humidity, light, and PM sensors, along with RTC and SD card modules for measurements and data logging. Voltage Sensor (BP 25) measures DC voltages from 0 to 25 volts. A voltage level is displayed as the most commonly used analogue output. To ensure accuracy when measuring voltage, a high input impedance is required to avoid any impact on the circuit under observation and prevent potential voltage drops. AC and DC currents can be measured using the Current Sensor (ACS 712) module. A variety of versions are available, each designed for different ranges. The sensor (SI7021) can accurately and efficiently measure temperature and humidity.

Furthermore, it can measure relative humidity from 0% to 100%. The light sensor (BH1750) is a highly multipurpose device that measures ambient light intensity within a wide range with high sensitivity. PM sensors PM5003 are widely used to detect particulate matter in the air. It emits, and measures scattered light to determine particle concentrations within a specific range. The RTC module (DS3231) keeps track of time and date in electronic systems. RTC modules have a built-in backup power source, usually a tiny battery, allowing them to continue operating. The sensors equipped in the data acquisition setup are calibrated with appropriate values in the datasheet. Figure 5, depicts the data acquisition sensors installed in the experimental setup to measure the real time data.

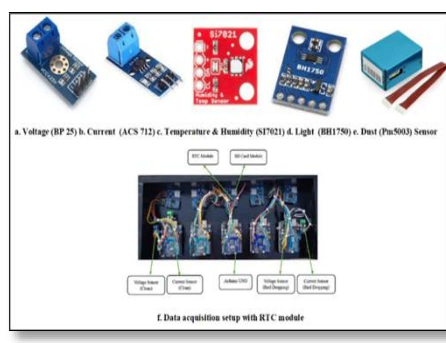

Fig 5: *Data acquisition sensor installed in experimental setup*

2.4. Analysis

After collecting all the data, a comparative study examined the panels affected by bird droppings. An extensive analysis was conducted to provide a thorough understanding of and assessment of the effect of bird droppings on the panel performance. By analyzing the data gathered from both situations, visible patterns associated with bird droppings were identified. The results of this comparison show how birds droppings impact a panel efficiency and effectiveness. Multiple linear regression was used to predict the degradation of the panels. This method explored the relationship between dust accumulation on PV panels and bird droppings on PV panels and their impact on the dependent variable. A quantitative analysis was conducted to determine how each factor contributes to the panels deterioration and evaluate their relative importance. Table I shows the electrical parameters of the photovoltaic panel used in the experiment. Different sensors are used to acquire data on physical parameters affecting PV performance. For the collection of real time data, a sensor

TABLE I: Electrical Parameter for PV Panel.

Parameter	Value
Maximum Power	10 W
Maximum Voltage	18 V
Maximum Current	0.56 A
Open Circuit Voltage	21.6 V
Short Circuit Current	0.59 A
Temperature Coefficient of	+0.1%/ °C
Temperature Coefficient of	-0.38%/ °C
Efficiency of PV module	7.9%

3. Results

An experimental investigation has been done to investigate the impact of bird droppings and soiling on the photovoltaic module. The experimental setup has been designed to estimate the number of bird droppings. experimental study was conducted for 25 days along the data of various parameters, including voltage, lux, temperature, and particulate matter) were acquired through a data acquisition setup. Figure 6, illustrates the initial stage of the experiment, where PV panels were intentionally exposed to bird activity in a dusty and humid environment. It was intended to examine the effect of bird droppings on the performance of solar panels.

Fig 6: *Initial state of the PV panels installed in the experimental setup*

An experimental setup has been installed to measure several factors, including average voltage, temperature, humidity, and irradiance. Table II depicts the experimental measurement taken in a clean configuration for twenty-five days.

TABLE II: Experiment setup measurements for clean PV panel configuration

Day	Average Power / Day (W)	Average Temperature/ Day (°C)	Average Humidity/ Day (%)	Average Irradiance/ Day (W/m^2)
1	3.06	36.78	59.02	304.35
2	3.01	35.34	60.78	298.95
3	3.01	35.54	66.45	287.82
4	3.12	36.23	68.63	272.03
5	3.06	36.89	67.87	271.37
6	3.09	36.12	65.89	285.11
7	2.99	36.75	66.69	234.81
8	2.99	34.78	68.91	192.14
9	3.00	36.95	68.23	182.36
10	3.06	36.45	67.45	247.26
11	3.07	37.09	62.31	252.13
12	3.01	37.12	59.45	251.58
13	3.09	36.23	61.45	279.85
14	3.09	35.12	65.32	307.22

15	3.07	38.33	62.31	305.83
16	3.06	40.19	57.36	272.87
17	3.07	38.77	55.71	296.61
18	3.09	36.71	63.33	287.99
19	3.07	37.39	64.71	274.57
20	3.06	36.56	72.45	273.12
21	3.07	35.45	72.31	280.98
22	3.05	36.12	74.23	273.09
23	3.07	35.48	67.53	290.63
24	3.05	34.45	72.45	267.79
25	3.05	34.89	72.69	273.25

The relationship between the voltage, days, and irradiance is depicted in Figure 7. The graph is three dimensional, including the factor of average voltages, irradiance, and number of days. The measurements observed in the clean PV configuration show that the clean panel did not show a significant decrement in average voltage concerning the progressing number of days and varying irradiance in the clean configuration of the PV panel. Along with that, it also depicts that varying irradiance has a significant impact on the average output in the clean configuration panel.

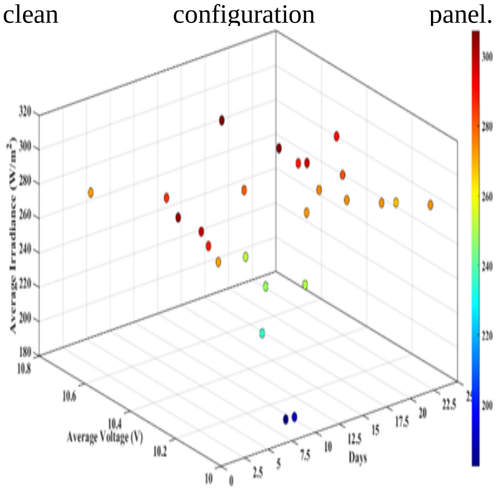

Fig 7: *Relation between (average irradiance) and number of days on clean PV panel.*

Figure 8 visually depicts the final stage of the experiment, illustrating a significant buildup of bird droppings on the PV panel. It highlights the contrasting conditions between the heavily soiled PV panel and the clean panel that received continuous cleaning throughout the study. The experiment aimed to assess the impact of bird droppings on panel performance in a challenging environment marked by dust, humidity, and avian presence. The findings from this research show the adverse effects of bird droppings on solar panel efficiency. They highlight the importance of regular cleaning to mitigate negative consequences associated with such deposits, ensuring sustained optimal performance in similar environmental conditions.

Fig 8: *Comparison between bird dropping and clean PV panel after 25 days of exposure to the environment*

Figure 9 shows the microscopic view of the bird dropping covered area on the experimental setup PV panel.

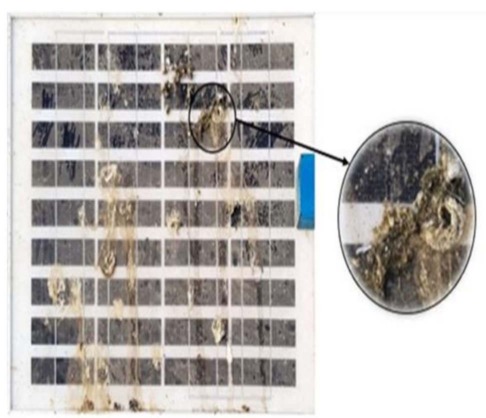

Fig 9: *Bird droppings on PV panel installed on experimental setup*

Figure 10(b) showcases the PV panel divided into smaller sections, accomplished through a grid pattern. This enables the area covered by bird droppings to be calculated, facilitating precise analysis of PV panel performance. By determining the specific affected area, the experiment produces a valued understanding of the level of this impact on PV panel functionality. In Figure 10(c), the experiment's final stage visually portrays a significant accumulation of bird droppings on the PV panel. This particular experiment aimed to assess how bird droppings affect and impede panel performance under challenging environmental conditions marked by dust, humidity, and the presence of birds. Figure 10 (d) depicts the PV panel, divided into smaller sections using a grid pattern. In particular, the section affected by bird droppings is shaded in the figure. This grid-based segmentation allows for precise calculation of the area covered by bird droppings on the PV panel. By quantifying the extent of dropping coverage, valuable information is gained for analyzing their impact on the panel's performance. The shaded area is a visual reference to accurately assess the proportion of the panel affected by bird droppings. Such analysis aids in understanding and evaluating potential degradation in power generation caused by accumulated droppings.

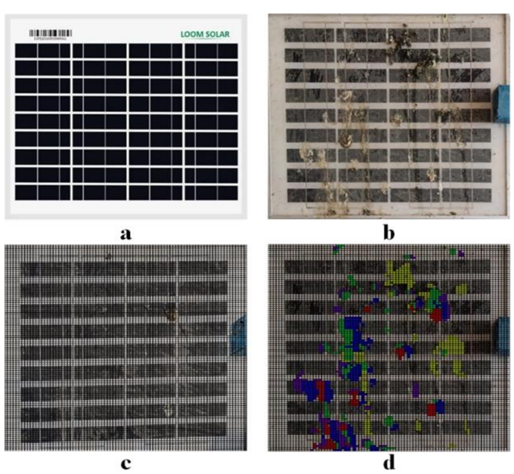

Fig 10: *(a) Clean PV panel (b) Bird dropping PV panel (c) Grid to measure bird dropping area (d) Grids shaded to calculate Dropping area Bird droppings on PV panel installed on experimental setup*

Table 3 depicts the average measurement of several factors, including average voltage, temperature, humidity, dust, and bird droppings. The experiment was conducted for twenty-five days. Initially, no bird dropping was observed for the first thirteen days due to the unfamiliarity of birds with the experimental setup environment. Later on, the bird dropping starts increasing after thirteen days. The relationship between voltage and dropping area is analyzed in Figure 10, where the dataset presented in Table III is subjected to multiple linear regression. This statistical approach allows for estimating voltage values based on specific dropping areas, which reveals that larger areas correspond to lower voltage readings. The graph portrays this inverse correlation, with a decrease in voltage as the size of the dropping area increases. Supporting evidence can be derived from plotted data points and the regression trendline that validates this observation.

Moreover, Figure 11 shows a three-dimensional graph that comprises three different variables that include (voltage, bird droppings, and dust). The graph shows that with the progression in time, the bird and soil accumulation increases, ultimately reducing the photovoltaic panel's output voltage. This demonstrates a positive correlation between these two variables as both are directly linked to each other. The plotted points on the graph visibly confirm this trend going up over time. From the given data, one can conclude that an increase in days corresponds to an increase in bird dropping areas. Multiple linear regression has been applied to estimate the maximum bird dropping. Equation (1) is obtained from the data in Table III.

TABLE III: Experiment setup measurements for PV panel exposed to bird droppings

Day	Average Voltage/ Day (V)	Average Power/ Day (W)	Average Temperature/ Day (°C)	Average Humidity/ Day (%)	Average Irradiance/ Day (W/m^2)	Average Dust/Day (ug/m3)	Dropping area (mm^2)
1	10.09	3.04	36.78	59.02	304.35	50.31	0
2	9.91	2.98	35.34	60.78	298.95	74.12	0
3	9.78	2.94	35.54	66.45	287.82	54.98	0
4	9.69	2.89	36.23	68.63	272.03	36.34	0
5	9.61	2.81	36.89	67.87	271.37	55.32	0
6	9.65	2.79	36.12	65.89	285.11	54.45	0
7	9.55	2.74	36.75	66.69	234.81	68.09	0
8	9.38	2.64	34.78	68.91	192.14	74.07	0
9	9.31	2.61	36.95	68.23	182.36	69.25	0
10	9.22	2.55	36.45	67.45	247.26	38.29	0
11	9.18	2.51	37.09	62.31	252.13	42.12	0
12	9.09	2.48	37.12	59.45	251.58	67.69	0
13	9.02	2.42	36.23	61.45	279.85	44.89	0
14	8.89	2.38	35.12	65.32	307.22	40.43	723.56
15	8.79	2.34	38.33	62.31	305.83	45.14	2401.41
16	8.75	2.32	40.19	57.36	272.87	50.01	2575.71
17	8.68	2.29	38.77	55.71	296.61	47.29	5501.29
18	8.48	2.21	36.71	63.33	287.99	48.65	10576.23
19	8.31	2.14	37.39	64.71	274.57	42.12	14487.44
20	8.05	2.08	36.56	72.45	273.12	53.32	19069.57
21	7.86	2.02	35.45	72.31	280.98	42.68	21789.50
22	7.34	1.91	36.12	74.23	273.09	54.35	27924.07
23	7.01	1.84	35.48	67.53	290.63	43.91	33074.25
24	6.89	1.79	34.45	72.45	267.79	55.01	35795.43
25	6.61	1.75	34.89	72.69	273.25	68.12	38746.09

Voltage=8.99+(0.074·Dust)+(-0.0001·Bird dropping area)⋯(1)

To find maximum bird dropping, voltage = 0 and dust = 52.23 ug/m³ (average value of dust for 25 days)

0=8.99+(0.074·52.23)+(-0.0001·Bird dropping area)⋯(2)

(0.0001·Bird dropping area) = 8.99 + (0.074·52.23)

(0.0001·Bird dropping area)=8.99+(3.86)

(0.0001·Bird dropping area)=12.85

Bird dropping=128500mm²

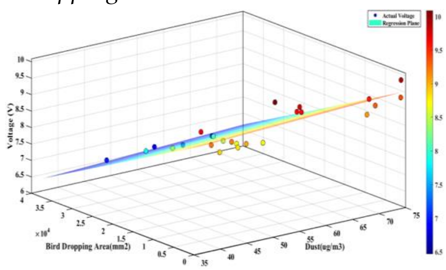

Fig 11: *Bird dropping impact on PV panel after 25 days of exposure to the environment*

According to the multiple linear regression equation above, the PV panel provides a voltage approaching zero when installed on an area of 128500 mm² occupied by bird droppings. Additionally, it shows that dust and bird droppings destroy the output of the photovoltaic panels within 82 days.

The short circuit current (I_{SC}) [45] and open circuit voltage (V_{OC}) [46] can be evaluated by using the expression below in equations 4 and 5.

$$I_{SC} = I_l + (ki\,.T2) \cdots (3)$$

$$I_{SC} = 0.59 + (0.001\,.34)$$

$$I_{SC} = 0.61\,amp$$

$$V_{OC} = V_{ref} + (kv\,.T) \cdots (4)$$

$$V_{OC} = 21.6 + (-0.0038\,.34)$$

$$V_{OC} = 21.4\,volt$$

The output efficiency of the PV modules [47] in both configurations, including clean and dusty, can be evaluated using the following expression.

$$\eta = \frac{P_{max}}{G.A} \cdots (5)$$

Where "*Pmax*" is the power obtained from the PV panel on each," *G*" represents the available irradiance, and "*A*" represents the area of the PV panel. The average values are taken for power and irradiance acquired from twenty days of experimentation in both configurations. Table IV compares output power efficiency between clean and dusty PV modules. The efficiency table shows that clean panels have better efficiency than dusty panels.

TABLE IV: Efficiency Comparison between clean and bird dropping PV module.

Formation	Avg Power/25 day **(W)**	Avg Irradiance/25 day **(W/m²)**	Output Efficiency **η** (%)
Clean	3.054	270.54	6.7
Bird droppings	2.412	270.54	5.2

4. Conclusion

The electricity demand is increasing, and nonrenewable resources are quickly depleted. Renewable sources, specifically photovoltaic energy, face several power and efficiency loss issues. This research is based on the experimental investigation of the impact of bird droppings and dust on the performance of PV panels. An experimental setup is designed to gauge the impact of bird droppings on PV panels. The experimental setup uses data acquisition sensors to log different physical parameters, including temperature, humidity, irradiance, dust, and voltage. Two PV panels were set up for the experiments; one was cleaned regularly. Rock pigeons were mostly seen in the site area; however, the droppings were of the same bird due to their increase in growth. The experiment was conducted for 25 days in a dusty and humid environment, which resulted in approximately 30% of the PV panel area being affected by bird droppings, which decreased the power output by 35%. Multiple linear regression has been applied to the data acquired during the experimental investigation. The statistical tool predicts that power degradation occurs due to bird droppings and dust, and following the data acquired from the experimental investigation, the output power will be zero for 82 days. The results obtained from this study help to adopt a cleaning pattern for industry and domestic users to increase the efficiency of the PV panel. Future research on this neglected problem can be implemented with cleaning methods that include robotic systems, water-based or dry cleaning, and combinations of these. Furthermore, conducting a comprehensive economic analysis will aid in optimizing PV system performance in such conditions by evaluating the effectiveness of different mechanisms and maintenance strategies.

AUTHOR CONTRIBUTION

Basit Ali for the major research idea and experiment design, Kaniz Fatima for writing and mathematical equation,Syed Awaiz Iqbal, Syed Sammer and Muhammad Nadeem designed and conducted the experimental setup and analysis.

DATA AVAILABILITY STATEMENT

Nil

CONFLICT OF INTEREST

No potential conflict of interest was reported by the author(s).

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