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The Effects of Soiling and Frequency of Optimal Cleaning of PV Panels in Palestine

Ramez Abdallah [1,2,*], Adel Juaidi [1], Salameh Abdel-Fattah [1], Mahmoud Qadi [1], Montaser Shadid [1], Aiman Albatayneh [3], Hüseyin Çamur [2], Amos García-Cruz [4] and Francisco Manzano-Agugliaro [5,*]

1 Mechanical & Mechatronics Engineering Department, Faculty of Engineering & Information Technology, An-Najah National University, Nablus P.O. Box 7, Palestine; adel@najah.edu (A.J.); salabdel@najah.edu (S.A.-F.); mahmoud.qadi98@gmail.com (M.Q.); shadidmontaser8@gmail.com (M.S.)
2 Department of Mechanical Engineering, Engineering Faculty, Near East University, Nicosia 99138, Cyprus; huseyin.camur@neu.edu.tr
3 Energy Engineering Department, German Jordanian University, P.O. Box 35247, Amman 11180, Jordan; aiman.albatayneh@gju.edu.jo
4 Department of Agronomy, University of Almeria, ceiA3, 04120 Almeria, Spain; amos@ual.es
5 Department of Engineering, University of Almeria, ceiA3, 04120 Almeria, Spain
* Correspondence: ramezkhaldi@najah.edu (R.A.); fmanzano@ual.es (F.M.-A.)

Abstract: The performance of photovoltaic (PV) solar panels is dependent on certain factors, such as dust effects. Even though Palestine's energy issues are well-known, no research has been undertaken on the soiling effect on solar energy generation in Palestine's climatic circumstances. The study's findings can aid Palestine's efforts to achieve long-term energy sustainability and solar energy use. Outdoor research was conducted in Tulkarm, Palestine, to explore the impact of dust on PV systems. The current study examined the impact of dust accumulation based on the Mediterranean climate. To accomplish this, a one-year experiment was conducted from 1 January to 31 December 2021. An 85-kW PV power plant at Tulkarm was utilized in the study. Knowing the efficiency reduction over time will aid in minimizing cleaning expenses by selecting the most appropriate cleaning interval. The results concluded that in January, February, November, and December, there will be a two-month cleaning period, monthly cleaning in March and October, as well as two weeks of cleaning in April and May. It may also be concluded that the plant should be cleaned weekly throughout the months of June, July, August, and September. This recommendation is necessary to maintain the PV panel plant operating at peak efficiency.

Keywords: photovoltaic panels; dust accumulation; solar energy; soiling effects; PV cleaning; sustainability; Palestine

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1. Introduction

The renewable energy industry is improving continuously and there is a big trend all over the world to use renewable energy to generate electricity and eliminate the need for burning oil and fossil fuel which adversely impacts the environment and, ultimately, human living conditions [1–4].

Interest in renewable energy is increasing rapidly due to the rising population on earth and the accelerated demand and use of energy. that the use of non-renewable energies is detrimental to nature when fossil fuels are burned causing emissions of gases like CO_2 and other harmful gases, which is related to dangerous problems such as global warming and air pollution. Therefore green clean energy like solar energy is an excellent alternative source, especially where it has many advantages, such as no major damaging effects on the environment, it is safe and cheap, and, finally, it is lasting [5–8].

The solar energy that hits the earth in one hour is nearly sufficient for one year of the Earth's requirements for energy but, unfortunately, some of this energy is lost when it is absorbed by some solid particles or reflected by water vapor. Additionally, for the solar panels, some of the radiation is absorbed by deposits and dust accumulation, which reduces the efficiency of the PV panels and it is from this perspective, that the idea of cleaning the PV panels originated [4,9,10].

Renewable energy created by PV panels is an efficient solution to the ever-increasing need for energy while also lowering hazardous emissions and the environmental implications that come with it [4,11]. According to REN21, the total worldwide solar PV capacity reached 627 GW in 2019, up from less than 23 GW only ten years ago, and an increase of 115 GW within one year from 2018, as seen in Figure 1 [12]. Thus, there is a trend toward the PV plants industry as a source of electricity since it is friendly to nature [9,10].

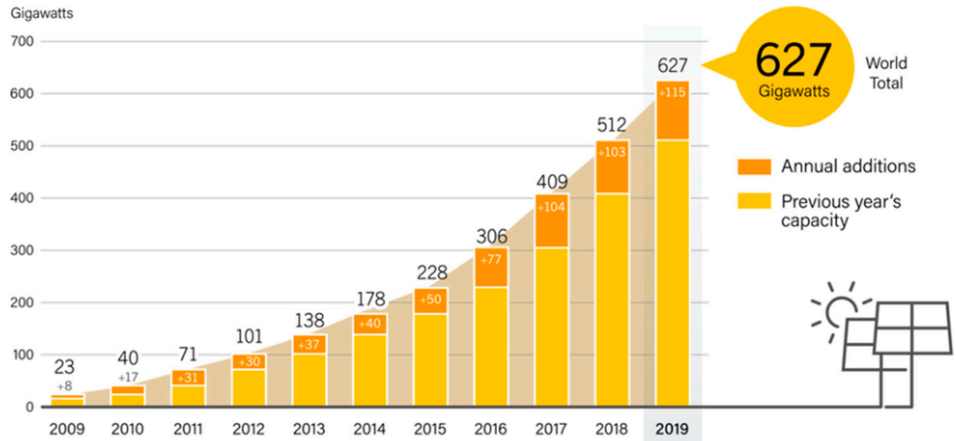

Figure 1. Global solar photovoltaic (PV) capacity (adapted from (REN21) [12], open access).

Solar energy as an investment is very efficient but it is not possible everywhere since the productivity of energy depends on the number of sunshine hours and the number of rainy days in a particular location, and because of this, the Middle East and North Africa have high productivity in the sector of solar energy [4,13].

Renewable energy investment is critical in Palestine since 98 percent of the country's energy is imported, which limits and controls a significant portion of the Palestinian economy. It is also critical for a country with a dependency on the electrical industry [14,15].

Palestine, in most regions, is exposed to around 3000 sunshine hours annually and has an annual average of 5.4 kW h/m^2 a day of solar radiation. This is a very good amount that can provide a good profit and dependable source for the electricity sector in Palestine [15–17]. Figure 2 shows the map of the West Bank and Gaza in Palestine.

In Palestine, PV panels were not widely used except in the last few years when thermal solar panels became so common in Palestine. Thermal panels are used for converting sunlight to heat while PV solar panels are used to receive sunlight and convert it into electricity. The solar PV panels are installed on the rooftops of buildings and also in the open wide places on the ground [18–20].

Main factors that affect the performance of PV modules include temperature, dust deposition, relative humidity, solar irradiance, wind movement, tilt angle, and shading [21–24].

Shading is one of the most important factors that affect the efficiency of PV panels. Shading includes anything that prevents the sun from reaching the cells in the PV module such as trees. and buildings [25,26]. Uniform shading of 50% on PV panels reduces the energy output by more than 60% which is a very high reduction in the outpower [25].

After temperature and solar radiation, dust deposition is the most significant factor that can affect a PV module's efficiency. The impact of dust is significantly dependent on the geographic location and local circumstances. As a result, determining a numerical figure for its negative effect is challenging [4,27–29].

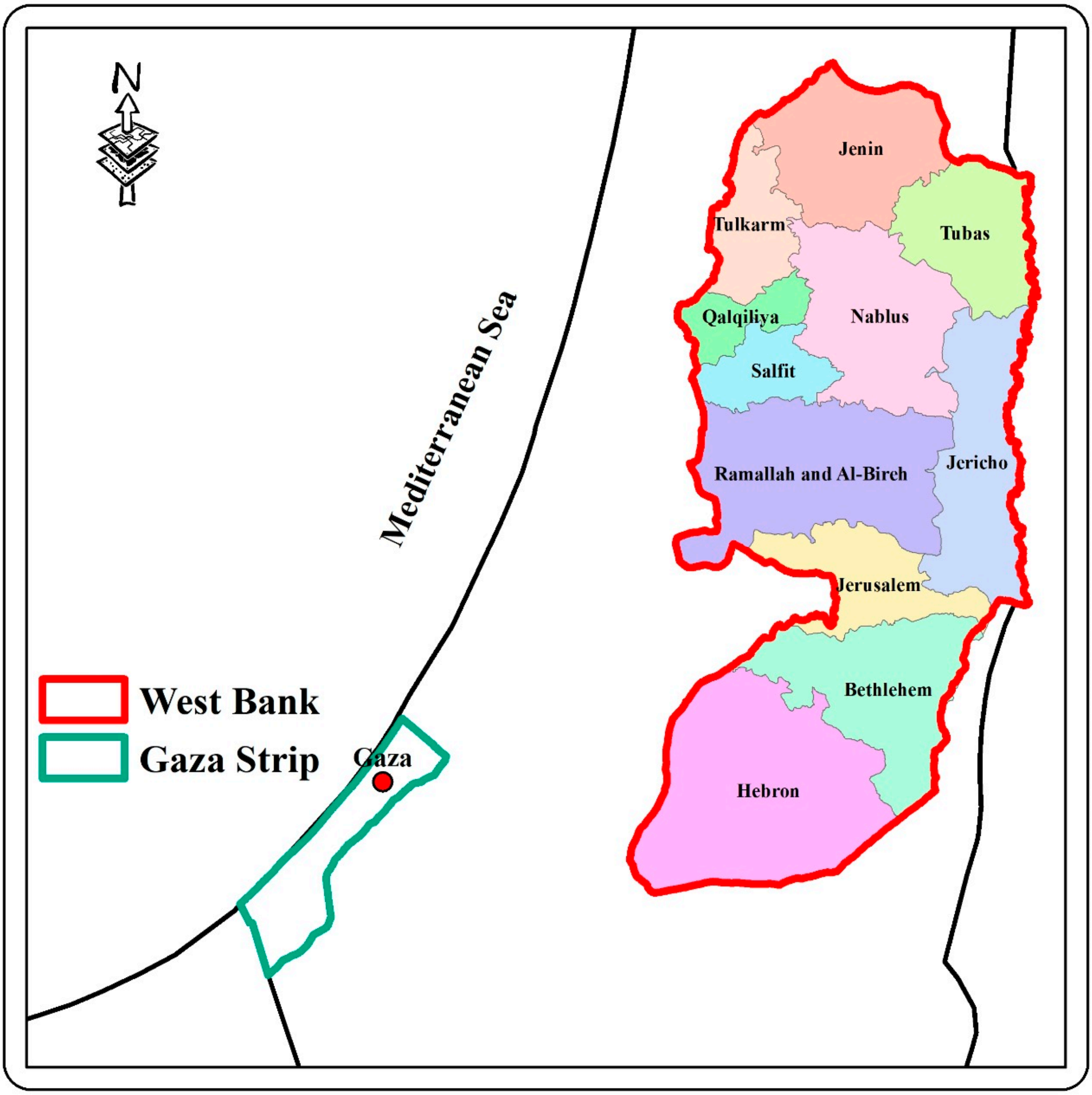

Figure 2. The main cities in the West Bank and Gaza Strip (**Palestine**) [15].

A variety of technologies and procedures have been used to clean solar PV devices and reduce the negative effect of soiling on PV efficiency. The most common cleaning methods are manual cleaning, robotic systems, automated water sprinkler systems, and self-cleaning methods [4,30–40]. Manual cleaning is a simple way of cleaning modules, especially on rooftops of houses and small-scale projects but it is not effective in large-scale projects. Manual cleaning is done by washing the surface of panels with a cloth or wiper in combination with water or other cleaning liquids and is a simple technique that does not involve high investment costs, however, it may damage the PV modules during the cleaning process because of unskilled workers [30–40].

The robotic system is considered the most in-demand cleaning technology, with waterless and water-based robot cleaning both suitable for large-scale solar plants, with the ability to remove hard dust and deposits [36–41]. The waterless method has a lower operational cost since it does not consume water [4,41]. Self-cleaning is a modification of PV modules by adding a coating of Nanofilm on the surface of the cells, there is no operator needed but the system has low reliability [42–48]. The automated water sprinkler system uses water to automatically wash the solar panels by nozzles connected to the panels so it is like artificial rain, the system is easy to install and the cycle of cleaning can be changed [49–53].

Figure 3 shows the main cleaning methods used for PV panels, while robotic cleaning could be considered an automated method or an independent major method [4,49].

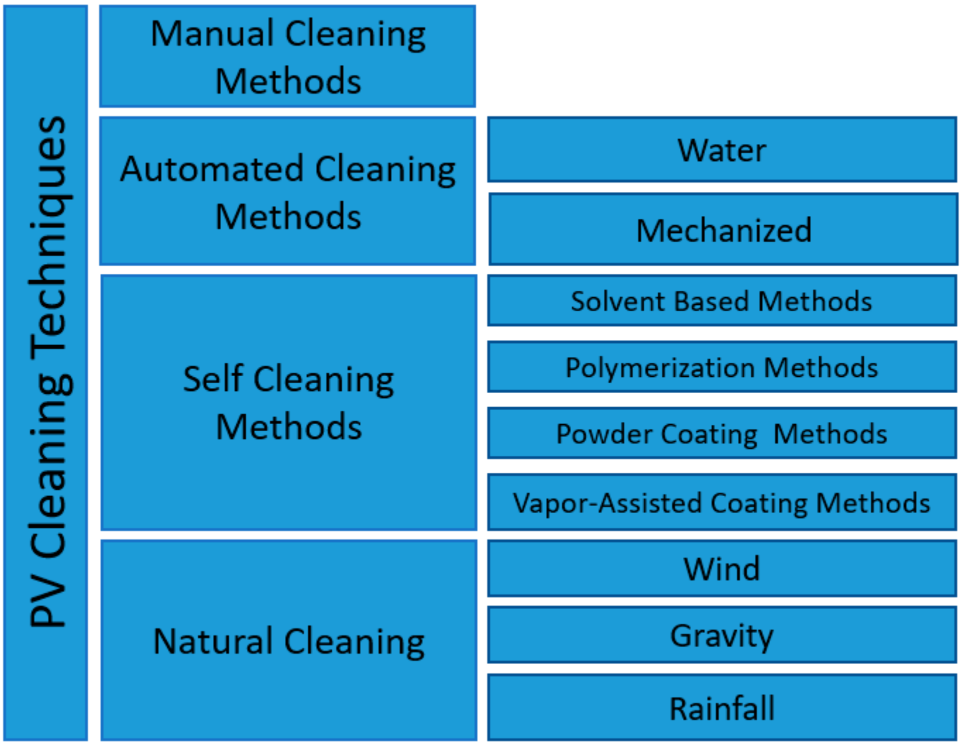

Figure 3. Major cleaning techniques for PV panels [4].

When choosing the best suitable cleaning method, in general, researchers recommend that manual or water sprinkler cleaning techniques should be used in the small PV stations, where the power production of panels in the system is up to 10 kW, while the robotic cleaning method and the coating is recommended for use in large PV stations where the power generation is more than 10 kW [54–56].

Many researchers are working on experimental studies to investigate the optimum cleaning method and frequency, with the cleaning frequency depending on the amount of dust, the presence of rainfall, and the surface of the PV panel where coated modules may be affected by some cleaning processes [23,25].

Del Pero et al. concluded that rain has a certain positive impact on the yearly performance of PV systems, with the average value during the spring/summer season ranging from 2% to 10%. Based on this context; such gain is greater than the more convective rainfalls that occur in the spring and summer seasons, which are characterized by intense precipitation and frequent alternation with partially-sunny conditions [3].

This scientific study was carried out in Tulkarm, West Bank, Palestine, under outdoor circumstances to see how dust accumulation impacts the panel's performance. For the whole year of the research, the cleaning efficacy of the system was examined by cleaning panels for various durations of time and leaving other panels uncleaned. Every one week, two weeks, one month, two months, and six months, the panels were cleaned. The output power data was then studied by comparing the power production of the weekly cleaned panels to that of other panels cleaned for different lengths of time and the uncleaned panels throughout the year, with promising findings.

2. Literature Review

Several studies on photovoltaic efficiency have been conducted in recent decades. Even though the PV system's performance has increased due to several improvements, environmental elements such as soil deposition, bird droppings, snow, and other debris that fall on PV panel surfaces cause inefficient performance. To achieve maximum efficiency and energy yield, an in-depth investigation of the impact of dust on solar panels is conducted. Table 1 shows the effect of dust in various locations around the world based on experimental studies, and it is clear that dust can cause a vital drop in the efficiency of PV modules, especially in desert climates.

Table 1. A review of scientific work related to the effect of cleaning on PV panels' performance.

No.	Author	Country (Year)	Cleaning Method	Cleaning Frequency	Test Duration	Main Result
1	**Al-Badra et al.**	**Egypt (2020)**	Self-cleaning (Nano-coating) mechanical vibrator.	Every 2 weeks for the coating panel, monthly for the combination of coating and vibration.	6 Weeks	The uncleaned panel efficiency decreased by 3.69%, the coating panel decreased by 2.74%, and the combination of coating and vibration panel's efficiency decreased by 1.45% [57].
2	**Shah et al.**	**UAE (2020)**	-	10 days 20 days 1 month 3 months	3.5 Months	The drop in electric power compared to a daily cleaned reference PV module was 3%, 5% 7%, and 13% for 10 days, 20 days, 1 month, and 3 months respectively [58].
3	**AL-Housani et al.**	**Qatar (2019)**	Microfiber-based cloth wiper	Weekly	6 Months	There was an average performance improvement in the power output of the cleaned panels compare to the case of unclean panels which was 7.7% in winter and 3.1% in summer [59].
4	**Kazem and Chaichan**	**Oman (2019)**	Water	Monthly	One Year	In the city of Muscat, there was a 52% reduction in power in the uncleaned PV module where the reduction in the monthly cleaning in the afternoon PV module was 34%, and it was 31% and 32% in the evening and early morning, respectively [60].
5	**Ahmed et al.**	**Jordan (2018)**	Filtered deionized water only	Monthly	10 Months	There was an average of 2.205% of the output power difference between the cleaned and the uncleaned panels [61].
6	**Bunyan et al.**	**Kuwait (2016)**	Water washing	Daily and monthly	One Year	The most affected months were April, May, October, and December with a reduction in the power of 15.07%, 13.74%,10.685%, and 8.742%, respectively compared to the cleaned panels [62].
7	**Hammoud et al.**	**Lebanon (2018)**	Robot cleaning	Every 2 Weeks	3.5 Months	There was an improvement of 32.23% in the output production power [63].
8	**Mohamed and Hasan**	**Libya (2012)**	Water washing	Weekly	4 Months	Weekly cleaning was sufficient to limit power loss in the range of 2–2.5% which was targeted in that study [64].
9	**Hammad et al.**	**Jordan (2018)**	Manual cleaning and natural rainfall	4 cleaning times with 3 frequencies: 53, 65, 74 days	192 Days	They found that the optimum cleaning frequency is between 12 and 15 days depending on ANN and MLR models. (Tilt angle was 26° in the experiment) [65].

Table 1. *Cont.*

No.	Author	Country (Year)	Cleaning Method	Cleaning Frequency	Test Duration	Main Result
10	**Urrejola et al.**	**Chile (2016)**	Manually using a brush with water	Monthly	2 Years	A monthly decay of 17.36% in the performance ratio, the suggested cleaning frequency was 45 days [66].
11	**Naeem et al.**	**USA (2015)**	Brush using water	Three times every year	10 Years including other studies	The annual soiling loss would be reduced from 1.9% to 1.2% when the cleaning is done 3 times per year [67].
12	**Moharram et al.**	**Egypt (2013)**	Non-pressurized water and a combination of anionic and cationic surfactants	Daily and once after 45 days	59 Days	The efficiency of the PV modules has decreased from 15% at the beginning to 8% at the end of the 45 days when cleaning with non-pressurized water, and the efficiency decreased from 15% to an average of 12% after 45 days of cleaning with a mixture of anionic and cationic surfactants [68].
13	**Sakarapunthip et al.**	**Thailand (2017)**	Manual	Once/2 Months	-	There was an increase in the output energy by 10% after cleaning [69].
14	**Cherif Aidara et al.**	**Senegal (2018)**	Waterless cleaning system	Daily	One Month	The uncleaned module efficiency decreased by 24.09% while the cleaned panels decreased just by 10.16% [70].
15	**Elminir et al.**	**Egypt (2006)**	-	-	-	There was an average decrease of 17.4% monthly in the PV efficiency [71].
16	**Jiang et al.**	**China (2011)**	-	-	-	PV efficiency drop was 26% [72].
17	**Cabanillas and Munguía**	**Mexico (2011)**	-	-	-	The amorphous module's maximum power was reduced due to dust in the range between 8–13% while the monocrystalline and polycrystalline modules had a reduction of maximum power between 4% and 7% [73].
18	**Wakim**	**Kuwait (2010)**	-	Monthly	-	PV efficiency decrease was 17% [74].
19	**Said and Walwil**	**KSA (2014)**	-	Monthly	-	PV efficiency decrease was 7% [75].
20	**Kaldellis and Kapsali**	**(Greece) (2011)**	-	-	-	Artificial dust (limestone) amount of 0.7 gm/m^2 decreased the efficiency by 0.6% While 1.2 gm/m^2 decreased the efficiency by 0.8% The natural air pollution with the same masses above affected the efficiencies by 0.1% and 0.17%, respectively. (the values are compared with a cleaned panel) [76].
21	**Weber et al.**	**Mexico (2013)**	-	-	-	For nearly 60 dry days, deposits and dust accumulation affected PV panels' efficiency by 15% while in the whole year, the reduction of efficiency was 3.6% because of the natural cleaning that comes from rainfall, this huge difference in reduction after rainfall is normal and expected in Mexico since there are 125 rainy days per year [77].
22	**Majeed et al.**	**Pakistan (2020)**	-	-	-	Power loss due to dust accumulation in the case of mono PV was 16.6% and 11.55% in the poly PV, both at an angle of 34.5°, and dust density of 4.6 g/m^2 [78].

Therefore, the cleaning process for PV panels is essential to recover the drop in PV performance. The concept of cleaning is related to some important factors, first, the periodic time of cleaning to obtain the required effect with the least amount of money and effort. Second, the method of cleaning, where the safety for both humans and panels should be taken into account. Moreover, the cleaning process itself is kept simple and efficient, and, naturally, there is rainfall, gravity, and wind speed that can help in the cleaning process [4,79–81].

Many studies have been conducted on the best way to clean photovoltaic panels, including determining the optimum cleaning period that provides the best performance at the lowest cost. Many conditions must be considered while analyzing the results, including rainfall, the photovoltaic panel location, ambient temperature, and relative humidity [82–87].

In the Middle East region, the worst-case scenario for solar panels is due to the large amounts of dust and the continuous presence of sandstorms, with the efficiency of solar panels reduced by up to 80% [88–91].

Globally, the cleaning effect of solar panels varies from one region to another, but it is most effective in desert areas [92–95]. Therefore, this should motivate researchers to conduct experimental studies to obtain accurate conclusions about the optimum cleaning method and period for each geographical region.

Recently, there has been a lot of focus on improving Palestine's energy sector by conducting experimental studies to help and improve the sector's ability to make the best use of the world's largest renewable energy source, the sun [96–98]. This study attempts to be one of the studies that can help Palestine make better use of solar energy.

3. Methodology

The dust impact is related to the air pollutants in the particular geographical region where the PV unit is installed. The city of Tulkarm was chosen to investigate the effect of soiling on the PV efficiency in Palestine and to determine the ideal time for cleaning; the location is displayed in Figure 1. Planning weekly or monthly cleaning cycles necessitates a thorough understanding of the climatic and environmental variables in the area. An experimental analysis will be undertaken in this study to compare performance efficiency.

3.1. Location of the Study

The investigation was conducted in a Mediterranean environment in Northern Palestine, in the city of Tulkarm (32.370 N, 35.108 E, 224 m) with global horizontal irradiation (GHI) of 5.45 kWh/m^2 at Ellar village in Tulkarm. Summers are dry and hot, and winters are wet and chilly in this Mediterranean environment. Indeed, the majority of Palestine receives roughly 3000 h of solar radiation each year, with typical solar radiation levels ranging from 5.4 to 6.0 kWh/m^2.day [15,99]. Climate characteristics in Tulkarm city in the year 2021 are displayed in Table 2.

Table 2. Climate characteristics statistics in Tulkarm city in the year 2021.

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
GHI (kWh/m^2)	87.74	102.11	154.06	187.55	225.49	243.46	247.35	224.34	184.82	145.01	103.83	86.64
Monthly Total Rainfall (mm)	145.5	124	18.5	9	0	0	0	0	0	1.5	38.5	49.7
Mean Monthly Maximum Temperatures (°C)	23.5	24	23.5	27.8	31.8	31.9	35.3	36.3	34.9	28.2	24.6	18.4
Number Of Rainy Days	9	8	8	2	0	0	0	0	1	2	5	3
Mean Monthly Wind Speed (Km/h)	5.53	4.05	4.24	4.98	5.53	5.16	5.35	4.98	4.42	4.42	3.50	5.53
Mean Monthly Relative Humidity (%)	69	60	56	64	53	63	63	65	63	55	56	69

3.2. Description of a PV System

The experimental research of PV cleaning was chosen at a location in Tulkarm, with a one-year length beginning on 1 January and ending on 31 December 2021. The PV power plant that will be utilized in the study at Tulkarm is an 85-kW project with 330 Wp Trina polycrystalline panels with a 29° tilt angle, four 25-kW inverters, and 64 PV modules for each inverter. The characteristics of the (Trina Solar 330) utilized in this investigation are shown in Table 3 under standard test conditions.

Table 3. Characteristics of (Trina Solar 330) in standard test conditions.

Maximum Power = 330 W	Open Circuit Voltage = 45.9 V
Short Circuit Current = 9.26 A	Maximum Power Voltage = 37.3 V
Maximum Power Current = 8.85 A	Power Tolerance = 0~+3%
Maximum system voltage = DC 1000 V	Module Application: class A
Nominal operating cell temperature = 45 ± 2 °C	Operating temperature: −40 to +85 °C
Weight = 23 kg	Dimensions = 1956 × 992 × 50 mm
Cell technology = Poly-Si.	Module Efficiency (%) = 17.01

3.3. The Procedure of the Experimental Study

The study was conducted on six groups of panels, each of which consisted of three modules with a different cleaning period: one week, two weeks, one month, two months, and six months, and the sixth group did not clean for the whole year. The first three PV panels on the right in the upper row were cleaned once a week, the next three panels on the left were cleaned once every two weeks, the next three PV modules were cleaned once a month, and the next three modules were cleaned once every two months, the next three modules were cleaned once every six months, and the final three PV modules were left uncleaned for the entire year as indicated in Figure 4.

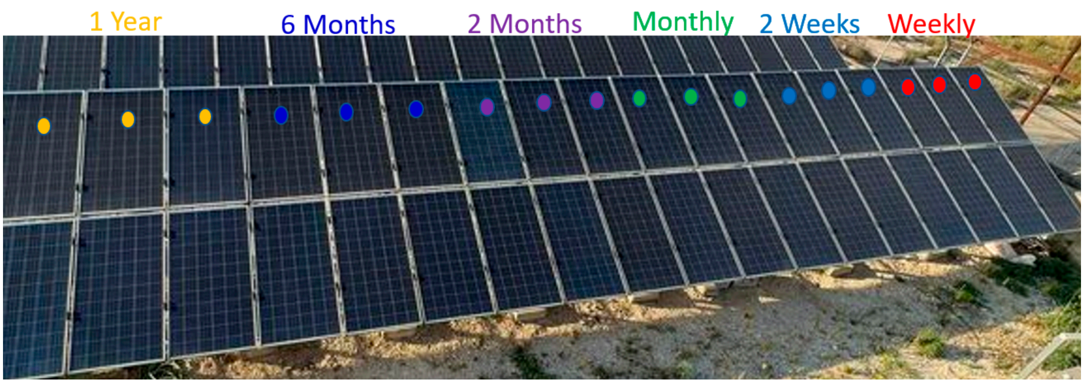

Figure 4. Shows the PV panels involved in the study.

In the beginning, all the PV Panels involved in the study were cleaned manually. Manual cleaning was conducted with water just before sunset, weekly readings of output PV power for each group of panels were taken, as well as the average power generated by one module was recorded. People involved in PV cleaning were taught the cleaning techniques so they would use the same procedure to reduce the human aspect. However, from January to December 2021, all of the PV panels involved in this research were subjected to the same unstable weather conditions.

Throughout the research, software named the Monitoring-Solar Edge was used to measure the power output of each PV panel and compare the output differences between groups. Table 4 shows the detailed power production of the panels participating in the study throughout the study year.

Table 4. PV panels output in KWh.

Date	Weekly	2 Weeks	Monthly	2 Months	6 Months	1 Year
7 January 2021	7.42					
14 January 2021	9.54	16.90				
21 January 2021	8.52					
28 January 2021	7.88	16.28	33.08			
7 February 2021	10.16					
14 February 2021	7.97	17.94				
21 February 2021	8.88					
28 February 2021	7.24	16.02	33.89	66.46		
7 March 2021	11.18					
14 March 2021	11.47	22.45				
21 March 2021	12.53					
28 March 2021	10.1	21.35	44.72			
7 April 2021	11.81					
14 April 2021	13.52	24.93				
21 April 2021	10.71					
28 April 2021	12.50	22.98	47.51	89.12		
7 May 2021	13.65					
14 May 2021	11.22	24.47				
21 May 2021	13.91					
28 May 2021	13.72	27.14	50.96			
7 June 2021	17.78					
14 June 2021	11.34	28.3				
21 June 2021	11.95					
28 June 2021	12.26	23.51	51.56	99.26	243.27	
7 July 2021	17.89					
14 July 2021	12.34	29.30				
21 July 2021	12.63					
28 July 2021	12.32	24.17	53.23			
7 August 2021	19.51					
14 August 2021	12.01	30.54				
21 August 2021	11.71					
28 August 2021	11.22	22.16	52.45	102.03		
7 September 2021	18.12					
14 September 2021	11.10	28.38				
21 September 2021	10.92					
28 September 2021	10.28	20.51	48.70			
7 October 2021	14.62					
14 October 2021	10.33	24.63				
21 October 2021	10.45					
28 October 2021	10.01	20.29	44.80	91.29		
7 November 2021	12.60					
14 November 2021	8.56	20.97				
21 November 2021	8.62					
28 November 2021	8.37	16.83	37.73			
7 December 2021	8.82					
14 December 2021	8.64	17.38				
21 December 2021	8.83					
28 December 2021	8.13	16.86	34.15	71.36	252.37	473.87

Figure 5 below shows the PV system used in this study.

Figure 5. The PV system used in this study is Tulkarm.

The percentage difference in power was calculated according to the following Equation [61]:

$$\boldsymbol{\Delta P} = \frac{\boldsymbol{Pc} - \boldsymbol{Ppc}}{\boldsymbol{Pc}} \times \mathbf{100}\%$$

where $\boldsymbol{Pc}$ is the output power of the PV panels cleaned weekly, $\boldsymbol{Ppc}$ is the output power of the PV panels cleaned for different periods (weekly, two weeks, monthly, two months, six months, and uncleaned for the entire year), and $\boldsymbol{\Delta P}$ is the percent difference between the two panels' power.

4. Results and Discussion

The results of power generation for the PV panels cleaned at different times are shown in this section; the cleaned panels with varied periods represent the panels cleaned at different periods (weekly, two weeks, monthly, two months, six months, and uncleaned panels for the whole year of study). The measurements cover the entire year of 2021, from 1 January to 31 December. The effect of the cleaning procedure is assessed by comparing the average power of the weekly cleaned and cleaned panels over different periods.

For the entire year, the output power differential between the weekly and two weekly cleaned PV panels did not exceed 1.8%, as illustrated in Figure 6. As a result, the power loss is unimpressive, according to the manufacturer's recommendations, which specify that a reduction of 2% in power efficiency necessitates cleaning. Because of the cleaning impact of rain during the winter season, it can also be concluded that the highest loss occurs in the summer months and the lowest occurs in the winter months.

For the entire year, the output power differential between the weekly and monthly cleaned PV panels is about 2.3%, as illustrated in Figure 7. As a result, a monthly cleaning operation may be sufficient to keep the system in good working order without incurring additional costs. Because the percentage difference did not exceed the operational manual instructions value of 2% in January, February, March, October, November, and December, there was no need for monthly cleaning because the losses were 0.85%, 1.06%, 1.22%, 1.34%, 1.10%, and 0.79%, respectively. However, the operational manual instructions value was exceeded in April, May, June, July, August, and September.

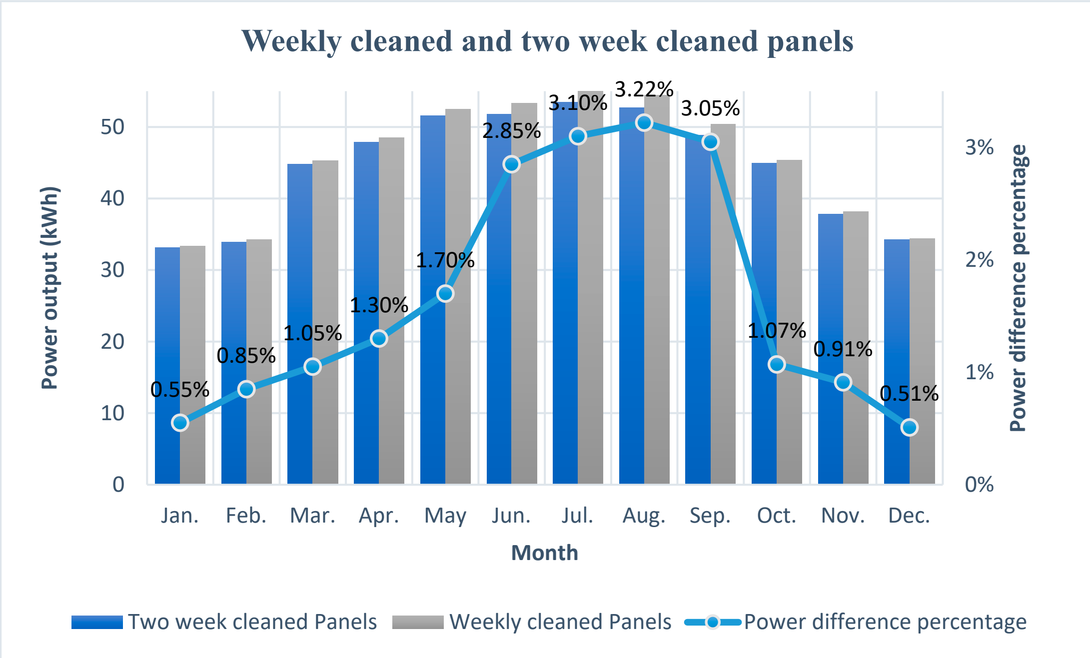

Figure 6. Power output and the percentage difference between weekly cleaned and two weeks cleaned panels.

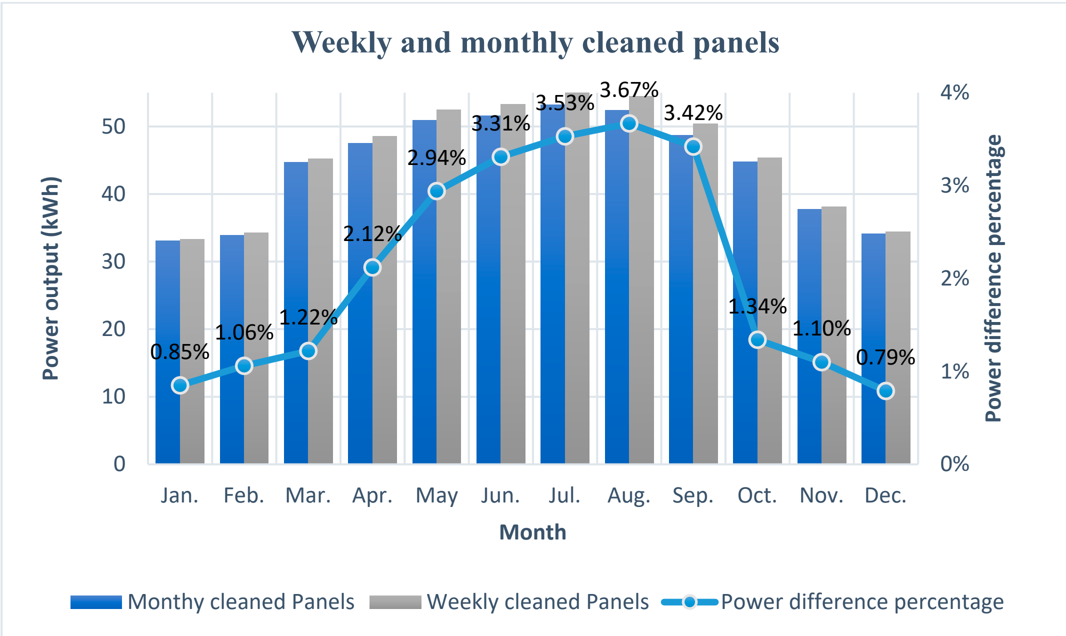

Figure 7. Power output and the percentage difference between weekly and monthly cleaned panels.

As shown in Figure 8, the output power differential between weekly cleaned and two months cleaned PV panels is approximately 4.73% over the duration of the year. That is considered a high percentage difference of power. The percentage difference in power was 1.72% for January and February combined, and 1.67% for November and December combined, which is still less than 2%. However, it was more than 2% for the remaining months, with 5.01% for March and April combined, 6.21% for May and June, 6.93% for July and August, and 4.74% for September and November, and these numbers are regarded as excessive according to the manufacturer's specifications.

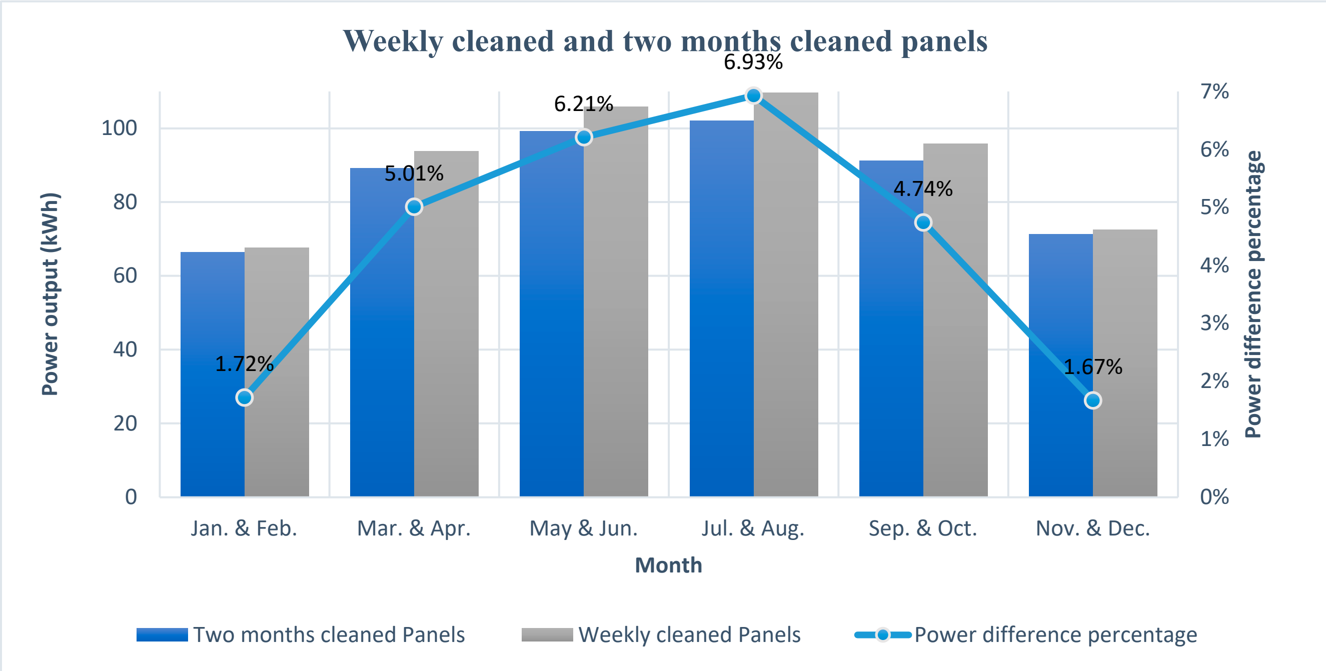

Figure 8. Power output and the percentage difference between weekly cleaned and two months cleaned panels.

As shown in Figure 9, the output power differential between weekly cleaned and two months cleaned PV panels is approximately 9.11% over the duration of the year. That is considered a very high percentage difference of power. It may be determined that the percentage difference in power between the first and second halves of the year was around 9%.

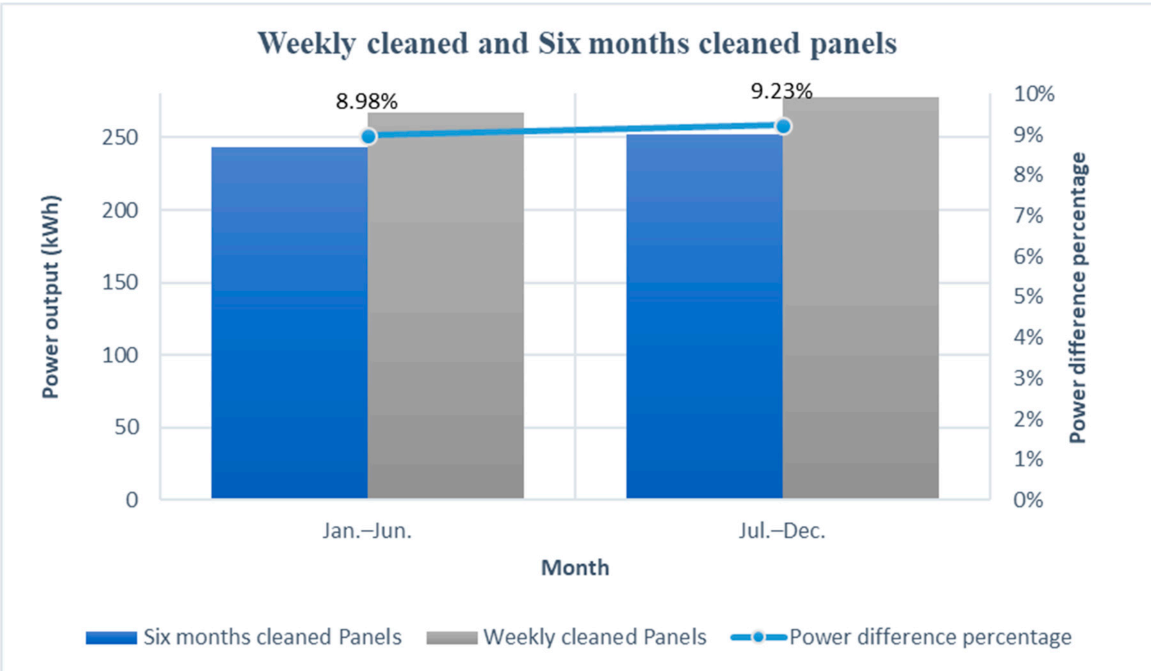

Figure 9. Power output and the percentage difference between weekly cleaned and six months cleaned panels.

As shown in Figure 10, the output power differential between weekly cleaned and yearly uncleaned panels is approximately 13%. That is considered a very high percentage difference of power. Finally, due to the ideal weather conditions and frequent rain in Tulkarm city during the winter season, the percentage difference between the panels that are cleaned weekly and the panels that had longer cleaning intervals was unremarkable in January, February, November, and December. In the spring and autumn seasons, however, the weather is dustier than in winter, but there is some rain. As a result, the power losses were slightly higher than in the winter months. However, given the dry and dusty weather conditions with little rainfall throughout the summer season, a major decline in power output might result in considerable financial losses with the 256 panels on site.

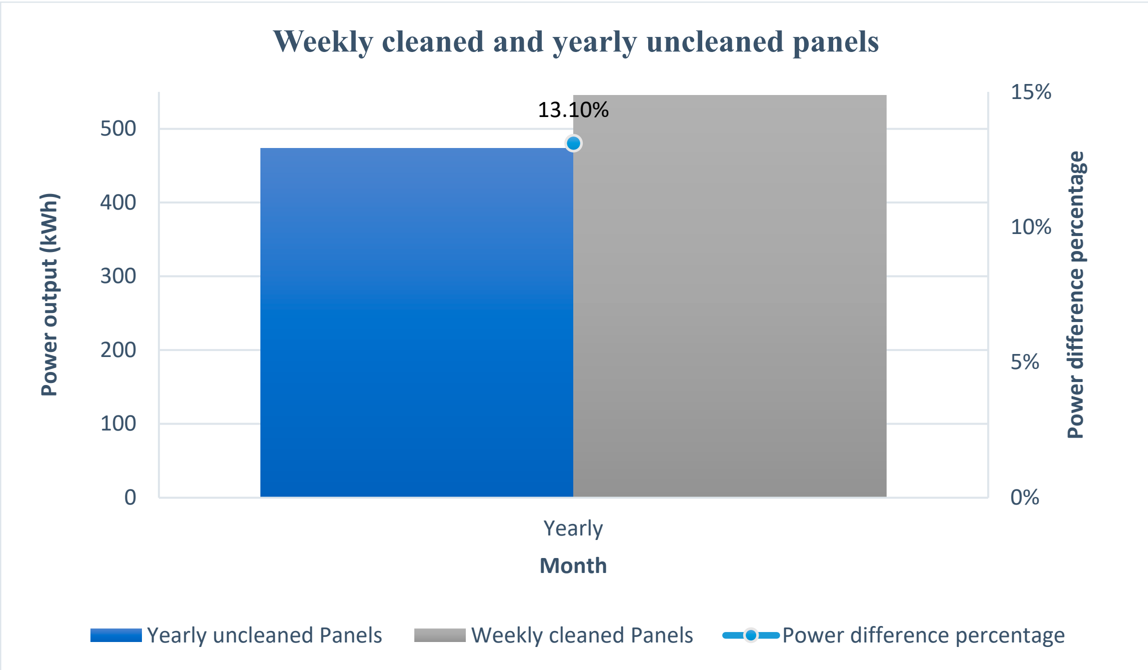

Figure 10. Power output and the percentage difference between weekly cleaned and yearly uncleaned panels.

5. Conclusions and Recommendations

Despite the fact that Palestine's energy challenges are well-known, no study of the soiling effect on solar energy generation in Palestine's climatic conditions has been conducted. The findings of this study can help Palestine's attempts to achieve long-term energy sustainability and solar energy utilization. Outdoor research was established in Tulkarm city to investigate the influence of dust accumulation on the performance of PV systems in Palestine. The influence of dust deposition in the Mediterranean climate was investigated in the present study.

To accomplish this, a one-year experiment was conducted, and the findings led to the conclusion that when compared to weekly cleaned panels, keeping the PV panels uncleaned for a year from 1 January to 31 December 2021, resulted in a 13.1% loss in power, and six months of unclean panels from January to June and July to December resulted in a power differential of 8.98% and 9.23%, respectively. While, two consecutive months of uncleaned panels in January and February, March and April, May and June, July and August, September and October, and November and December resulted in 1.72%, 5.01%, 6.21%, 6.93%, 4.74%, and 1.67% difference in power, respectively.

In January, February, March, April, May, June, July, August, September, October, November, and December, leaving the PV panels unclean for a month resulted in average losses of 0.85%, 1.06%, 1.22%, 2.12%, 2.94%, 3.31%, 3.53%, 3.67%, 3.42%, 1.34%, 1.10%, 0.79%, respectively. Finally, cleaning PV panels every two weeks versus weekly cleaning resulted in a 0.55%, 0.85%, 1.05%, 1.30%, 1.70%, 2.85%, 3.10%, 3.22%, 3.05%, 1.07%, 0.91%, and 0.51% reduction in power generation in January, February, March, April, May, June, July, August, September, October, November, and December, respectively.

According to the operating manual, a 2% decrease in power efficiency necessitates a cleaning operation for the entire plant. As a result, knowing the efficiency reduction over time will aid in minimizing cleaning expenses by selecting the most appropriate cleaning interval. Therefore, in January, February, November, and December, there will be a two-month cleaning period, and monthly cleaning in March and October, as well as two weeks of cleaning in April and May. It may also be concluded that the plant should be cleaned weekly throughout the months of June, July, August, and September. This recommendation is necessary in order to maintain the PV panel plant operating at peak efficiency.

It might also be recommended that further studies be carried out at intervals of more than a year and that these experiments be carried out in a number of Palestinian cities. In addition, the influence of several parameters on soiling, such as temperature, humidity, wind speed, and PV tilt angle should be investigated. Moreover, some environmental data, such as air quality conditions, should be investigated so that the effect of these elements can be related to cleaning frequency. The natural degradation of PV efficiency is also a worry that should be explored. Photovoltaic cleaning units require water consumption and have other economic consequences. Therefore, it is useful to study the economic cost of the different cleaning methods and determine which method is better and if the cost of cleaning is commensurate with the amount of energy gained as a result.

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