Original Research Article

Elemental composition of Dust Particles and Influence of Dust Addition on Photovoltaic Module Performance

ABSTRACT

There is an excellence prospective for solar power practice in Nigeria by engaging solar photovoltaic (PV) units. Addition of dust on solar antennae and PV elements is a pronounced worry owing to different dust particles fouling on the module. The recitals of such devices are considerably suffering from dust addition. Dust samples involved during this study came from ash, cement, rice husk, brick dust, and sand. This paper therefore, reports the outcome of a research work on the elemental composition of dust particles and influence of dust addition on the maximum power, efficiency and performance ratio of a 3 W polycrystalline solar PV module. The electron dispersive x-ray analysis of the collected dust samples revealed silicon having the highest percentage weight composition while sulfur and nitrogen records 0 % in most of the sample apart from rice husk. The experimental measurements were conducted outdoor under 470, 715 and 756 W/m^2 solar irradiation levels. Results indicated that dust addition on the solar PV module negatively affects the output power with cement dust proffering highest effect due to high percentage weight of carbon present in it. The research work revealed that solar PV modules polluted by dust particles for a period of time experienced a significant decrease in their efficiency and performance during operation. Accordingly, it is recommended that installed PV modules be cleaned routinely as dust particles hid on the solar panel naturally. Many areas have to be covered in future like construction sites, agricultural land and many more as solar power is growing exponentially in Nigeria.

Keywords: Elemental composition, dust addition, maximum power and performance ratio

1. INTRODUCTION

The swelling implication in demand for electricity in Nigeria and lots of other developing nations of the world is always same and perhaps on a high side since the inauguration of electricity [1]. Today Nigeria's energy blend is chiefly dominated by the electricity produced from the hydropower and gas plants operated using fossil fuels as the energy source. The assembly of electricity via fossil sources is the main cause for industrial pollution which is not only causing threats to the environment but also affecting the quantity of inadequate old-style energy sources, e.g., petrol, diesel, and coal etc. Besides, in today's epoch of globalization, the variation in climate is among the threatening tasks faced by every country of the world where Nigeria as a nation is within the same trap. Therefore, the search for the assembly of unpolluted energy sources that could power our economy has directed to the look for energy sources, termed renewable energy (RE) sources. These RE sources are natural and may be restocked over a period of time, examples include wind, biofuel, geothermal, tides and solar [2]. Sun is one among the foremost important sources, where it irradiates our planet by a solar power which is 8000 times quite the present rate of worldwide consumption energy [3]. One among power conversion technologies is 'Photovoltaic Method'. This method directly converts the sunlight into electricity employing unique devices refer to as photovoltaic cell [4]. The gains of RE over non- RE sources aside from future cost reduction in electricity with decrease dependence on national grid power is; its reliability, cleanliness and deploy ability mostly everywhere, without the expensive power lines. Pollution wise, RE is environmentally friendly and permanent in nature [2,5]. By considering the gains of this free, natural plentiful energy source, solar PV technology is becoming the supreme encouraging hygienic energy assembling system and the fastest rising RE technology due to a remarkable decline in price and noise pollution free during operation [6-7]. Yet, an undecorated challenge is fronting this technology during its operation, because of the effect of various sorts of dust materialization [8]. Primarily dust affects the PV panels' in two ways. Firstly, dust directly relaxes on the solar PV panels thereby obstructive the sun's rays from reaching the panels' cells. Secondly, the sensor for tracing solar insolation may be shielded by dust [9-11]. Consequently, maintenance and cleaning schedules for PV amenities are suggested in previous studies [12-14].

1.1 BRIEF REVIEW OF SIMILAR RESEARCH WORKS

Previous researches have shown that power losses caused by dusting, especially in areas where there is little rainfall can vary from 10% to 70% on different reasons which affect the PV system performance, [1, 4, 12, 15-17]. Some researches categorized and conferred the dust problem based on its physical, chemical and biological properties [17-18]. Dust has been investigated within the last decades using several approaches [9, 13, 19-21]. Additionally, the relation amongst dust addition, tilt angle and orientation of PV modules has been investigated [22]. Other studies have focused on dust issue in connection with temperature, wind, humidity [23-24].

One among the pioneers within the study of dust's effect on photovoltaic cell performance [25a, b], investigated the consequences of dust on solar PV modules based on the chemical and physical properties. The study reported cement particles effect on PV module as the most important aspect.

Fountoukis et al. [26] probed the influence of dust particles in terms of size on the PV cells in Doha, the study revealed that the deposition of small-size particles causes greater reduction than large-scale particles even though they are distributed more regularly on the surface of the cells. In a similar strain, Hussain et al. [2] reported that the smallest dust particle lumps more solar radiation thereby reducing the performance of solar panels.

Karmouch & Hor [27] reported 10% reduction in solar cells efficiency for an exposure time of 16 weeks by regular dust buildup during an outdoor test measurement within Jazan region. Darwish et al. [28] reported the direct influence of dust related with other factors on PV performance. The PV module surface recorded 4.4 % decrease in electrical power daily when roofed with dust; and in lengthy days devoid of rainfall might be above 20%.

Rajput & Sudhakar [29] while aiming on factors like solar radiation, proficient operating plans, map out plus dimensioning of solar PV systems established that dust particles meaningfully lessens the efficacy of the panel. Darwish et al. [30] revealed that ash has a greater negative impact on PV voltage reduction of about 25% compare to sand, calcium carbonates, red soil and silica on the performance of polycrystalline PV modules.

Rahman et al. [9] investigated the effects of natural dust on the act of PV panels in Bangladesh and found reduction in efficiency of the panel to be 35% in a month. Javed et al. [31] in Doha studied the rate of dust accumulation, elemental composition and the average particle size of the deposited dust. The study revealed that calcium is the most abundant element followed by silicon, iron, magnesium, aluminum and gypsum, which is a secondary component in the studied area. Roy [32] reported that the carbon dust can reduce the system efficiency more than partial shadow effect.

A major study on dust effects on the glass cover of a PV module by Said & Walwil [33] recorded a 35 % decrease in spectral transmittance. Mekhilef et al. [34] interrelated amongst thickness of dust accumulated on PV module and inconsistency in proficiencies of composite climate, a significant reduction in PV module output of about 10-20 % by dust accumulation was inferred. Sulaiman et al. [35] reported that external resistance could reduce PV performance by up to 85% however, concluded that water droplet from rain would not affect significantly the performance of PV modules.

Ekici & Kopru [5] investigated PV system cable losses and their effects. The study inferred that cable losses negatively affect the peak power of PV and the percentages of these losses exist as a function of the cross section area of the cables. Kumar et al. [1] predicted 26.5% energy loss and degradation rate within 0.6 to -5% of a 200 kW roof-integrated crystalline PV systems under certain climatic conditions in India per year. Goossens & Kerschaever [36] reported that PV cells performance is greatly affected by the accumulation of fine Aeolian dust particles.

Adinoyi & Said [17] in their experiment recounted that dust particle size scattering and shapes influence the shielding effect of the dust on PV module surface; hence the power output. Kazem & Chaichan [24] studied the physical and chemical properties of manual deposition on PV modules in an indoor laboratory environment in North Oman. The study reported 30-40% reduction of power output due to dust addition particularly; dust samples with the highest humidity content, specific gravity and elasticity index caused the greatest worsening of PV performance.

To crest it all, solar energy is a hygienic and obtainable source of energy for electrical generation in rural and remote areas. This has been confirmed by many important studies in the literature [37]. Currently, the Federal University of Agriculture, Makurdi-Nigeria is accessing uninterrupted electricity power due to the installed hybrid solar power in recent time. In the meantime, little literature is available from previous studies capturing dust influence on PV output performance on the local area within Nigeria. Though, the core shortcoming of a PV system is narrow to efficiency. Besides, solar PV panel's pollution by dust particles is a function of location [30]. For that reason, applying a common model in all locations becomes independent. Since installation design of solar systems anywhere in Nigeria as it stands, do not consider many of these losses, it is pertinent to investigate the elemental composition of different dust types commonly found in Makurdi and their effects as these remotely affect the output performance of solar PV module during operation. In this paper therefore, elemental composition and influence of dust addition on the efficiency and performance ratio of a solar PV module of known power rating was assessed using five different samples.

2.0 MATERIALS AND METHODS

2.1 Materials and dust sample preparation

The dust samples (ash, cement, rice husk, brick dust, and sand) were collected from different parts of Makurdi. Samples like brick dust and cement were collected from factory and construction sites along Sen. George Akume way and the ash was domestically gotten from burnt firewood. The rice husk was collected from Rice Mill at

Wurukum where rice is being cleaned from rice bran and sand was gotten from the playing ground, South core of the Federal University of Agriculture, Makurdi. Samples of the collected dust were weighed using METTLER PM2500 weighing balance to determine dust density (dust weight shared by module surface area) and characterized using Energy Dispersive Spectroscopy (EDX 800 spectrometer Skyray Instrument) to determine the nature of each dust elemental composition. Fig.2. displays the percentage weight of elements per dust sample as measured using EDX.

2.2 Methodology

In an outdoor test-stand mounted in front of the Physics Laboratory at the Federal University of Agriculture, Makurdi (latitude 7.77^{o}N, longitude 8.62^{o}E), the solar PV panel was exposed to natural sunlight tilted at 45^o facing northwards with the ambient temperature variations between 22 to 33^{o}C during the month/year in Makurdi. Display in Table 1, is the specifications of the experimented solar PV panel. The test started with the study of a clean PV panel without dust (0 g/m^2) for output power comparison purposes. Subsequently, 5.00 g (347.22 g/m^2) of dust was distributed uniformly over the module surface to ensure homogeneity. No scientific theory in existence proved this homogeneity. But in nature, homogeneity occurs randomly. In this research, all experiments tried to distribute each dust sample in a homogeneous way using a flour strainer as adopted by previous researchers [2, 38].

Table 1: Polycrystalline PV module specifications (DP-Li21 China)

Dimensions	
Module dimensions (mm x mm)	180 x 80
Cell dimensions (mm x mm)	30 x 20
Cells per module	24
Cell area per module (m^2)	0.0006
Electrical specifications	
Max Power at STC* (W)	3 $\pm$5%
Open circuit voltage, (Voc) in V	7.2
Short circuit current (Isc) in mA	568

Key: Standard test conditions (STC): irradiance 1000 W/m^2 and temperature 25 ^{o}C.*

To measure the intensity of the sunlight reaching the module, a Solar Power Meter (TENMARS TM-206) was used. All points' measurements were taken in time intervals of 1 hour, starting from 10:00 am to 12:00 pm per day for five days in the month of February, 2021 when no rainfall was observed in Makurdi. For the measurements of maximum power output, a rheostat and (for voltage and current monitoring) were connected to solar PV module as shown in Fig.1. The voltage *(V)* and current *(I)* values in each case were obtained through the multimeters by varying the resistance using the rheostat in the PV experimental circuit, which directly affects the voltage and current in the circuit. The maximum power outputs in each case were calculated as presented in equation (1). The data collected for five days from the dusty and clean solar panel was averaged for each sample to obtain final values for solar irradiance, *V, I, I-V* curves and their corresponding maximum power output. Therefore, only the average values have been reported in this article.

Fig.1.Schematic Diagram of the Experimental Setup

For the monitoring of ambient temperatures, Redmi 9C (Model: M2006C3MG, Xiaomi, China) with an infrared blaster was used. Since infrared thermometer is considered a good approximate of the cell operating temperature. The cleaning method of the filthy module may be with a fine brush [39], which was also adopted for this study in cleaning the polluted panel after each pollution and measurement. The experimental setup design and measurement of performance results in terms of current and voltage were taken in real-time condition under similar conditions of solar irradiance and ambient temperatures. The graph plots from the collected data were done using the Origin software.
The power (P) and efficiency (η) can be calculated using the following formulae [8]:

$$P_{max} = I_{max} V_{max} \quad (1)$$

where I_{max} is the maximum current in amperes in amperes and V_{max} is the maximum voltage in volts. The efficiency of the solar module is determine as stated in equation (2)

$$\eta = \frac{P_{max}}{E \times A} \text{ x } 100\% \quad (2)$$

where P_{max} is the maximum power output created by the solar PV module, E is the available global irradiance at module tilt in W/m^2 , and A is the surface space of the solar PV panel.

3. RESULTS AND DISCUSSION

3.1 Elemental composition analysis

Elemental composition of dust samples in terms of percentage weight of each element present per sample as presented in Fig.2 were analyzed using the EDX spectroscopy. The result shows that silicon makes the largest content of 40 % and 24.5 % for brick dust and rice husk respectively, followed by 19.5 % aluminum for brick dust, 14.5 % carbon and 11.5 % potassium for cement sample, while 13 % calcium was observed for ash. Sulphur and nitrogen recorded the smallest content of 0 % in almost all the samples except for rice husk which is 0.2 % as illustrated in Fig.2. This composition is probably influenced by the source of these test samples and human activities within the source locations. In general, the result revealed some elements similar to those found in literature [17-18, 25b, 24]. However, elemental analysis of rice husk and other samples using proton-induced x-ray emission (Pixe) spectrometry revealed many other elements [40]. This is because the Pixe has higher resolution compare to EDX 800. Besides, the physical nature of dust and its elemental composition are dominated by the region in which it is studied [27].

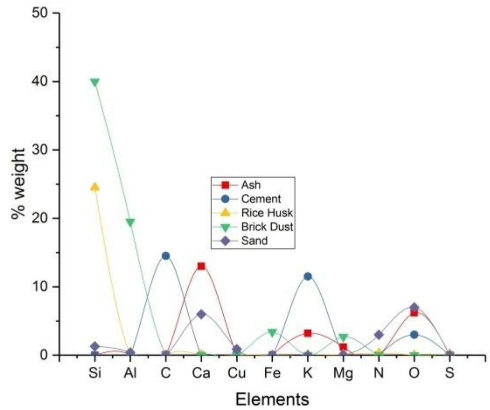

Fig.2. Elemental composition of the dust samples

3.2 Current-Voltage Characteristics

Fig. 3 shows the *I-V* curves for the experimented 3 W solar PV module at three different solar irradiations (470 W/m^2, 715 W/m^2 and 756 W/m^2) for the selected dust samples each of density 347.22 g/m^2. It can see clearly that the addition of dust on solar PV module reduces the short-circuit (Isc) and I_{max} for the *I-V* characteristic when compare with the Isc of the solar PV module with no dust. The situation is worse when considering the *I-V* curve of 470 W/m^2. This situation is due to the lower solar irradiation reaching the PV module at 10 am during the measurement period as dust particles prevents much rays in reaching the module especially at lower solar irradiation levels [35]. For more details, see the plotted peak power reductions with corresponding efficiency in Figure 4a-c. For irradiations of 715 W/m^2 and 756 W/m^2, the *I-V* curves for all the five samples are relatively close to each other. Comparatively, at 470 W/m^2 the *I-V* curve for no dust records a reasonable variance from all the test samples. This is possibly attributed to dust influence which was considerably more active in hampering the light from hitting the solar PV panel's surface at lower solar irradiation levels [11, 27]. Generally, the plotted *I-V* curves revealed a similar trend with that of typical PV solar panels. Since the area under the curve represents the maximum electrical power of the solar PV system. To sum up from Fig.3, the maximum power could be generated when the panel is unpolluted by dust. With the addition of dust, the space within the curve will shrink, indicating a decrease in energy generated. The results, also agre e with previous works of [11, 17, 41].

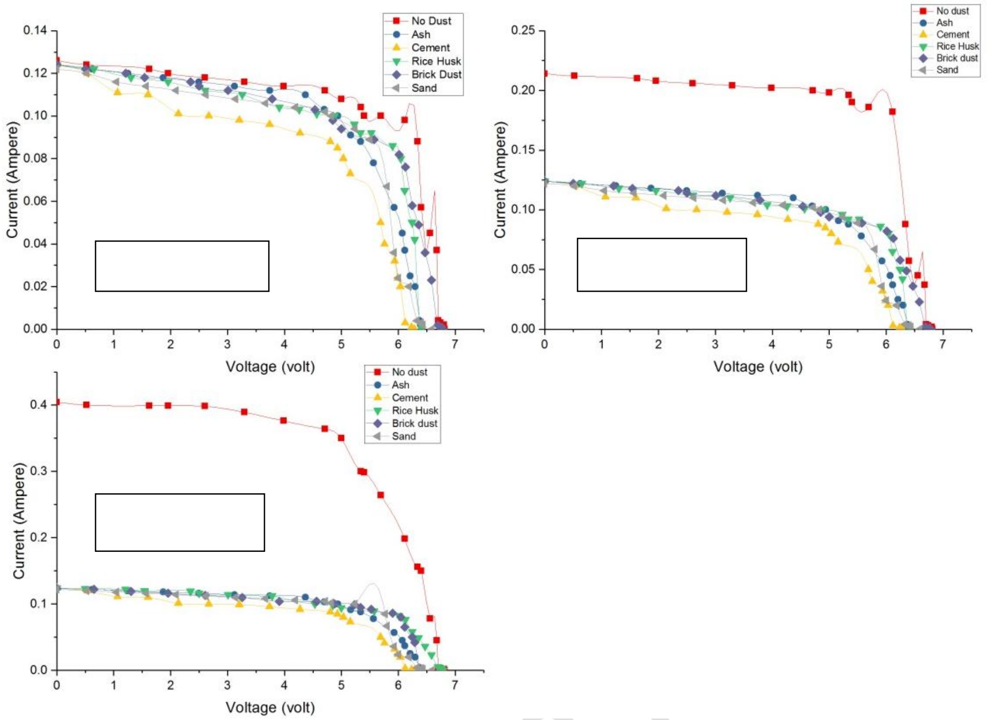

Fig.3. I-V characteristics for three different solar irradiations

3.3 Dust Effect on Maximum Power Output and Efficiency

From Fig.4, the influence of dust on the solar PV module is quantified by presenting the maximum power outputs and efficiencies of the solar PV module under each experimental condition. From Fig.4a-c, the highest maximum power occurred when the panel was not covered with dust.

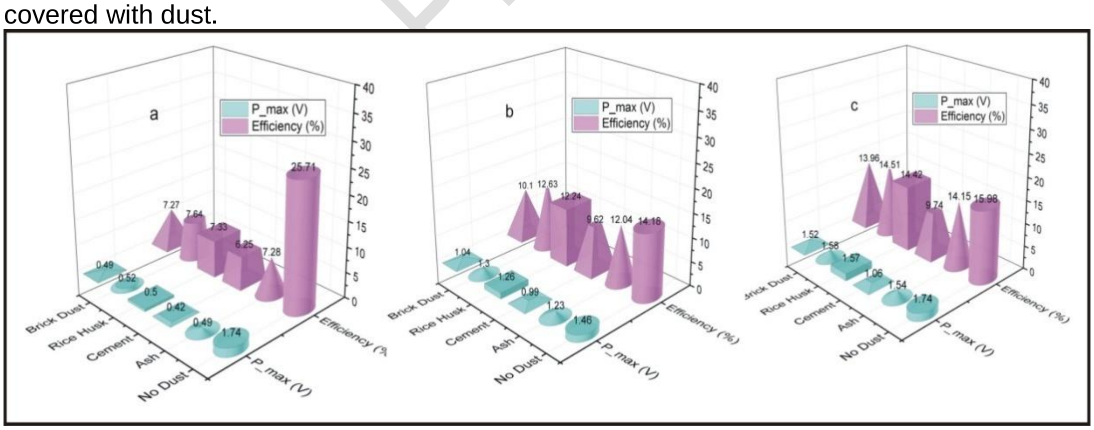

Fig.4. Maximum Power Output of Dust Samples with Efficiency at (a) 470 W/m^2, (b) 715 W/m^2 and (c) 756 W/m^2

The cement and sand dust reduces the maximum power significantly for all case of solar irradiations. If the effects at 470 W/m^2 were to be excluded, the brick dust sample records the highest maximum power of 1.30 W at 715 W/m^2 and 1.58 W at 756 W/m^2 followed by rice husk with 1.26 W at 715 W/m^2 and 1.57 W at 756 W/m^2. This might be due to the low percentage weight of carbon content found in these samples, as carbon blocks more solar irradiance when its percentage weight is much in any dust sample [32]. However, rice husk and brick dust exhibited almost a similar reduction in maximum power. This is as a result of the closeness in percentage weight values of elements found in these samples. The lowest reduction in maximum power was found to be 0.42 W for cement at irradiation levels of 470 W/m^2. The highest calculated efficiency was observed to occur at 756 W/m^2 for all the tested dust samples. Ash recorded 14.15 %, cement 9.74%, rice husk 14.42 %, brick dust 14.51 % and sand 13.96%. Considering the whole of Fig.4, it is observed that cement particles has much negative effect on the output performance of the PV module due to high percentage weight of carbon. The result also agrees with works of [17, 25a-b, 38]. Conversely, the case of no dust addition records the efficiency of 25.71 % at lowest solar irradiation of 470 W/m^2. Besides, from Fig.4a & c, the values of maximum power are in equal value of 1.74 W; though, the solar irradiation values differ. The cause for this is not well understood and more research is recommended for the future.

To crown it all, there is a clear reduction in both the maximum power output and efficiency for each test condition if compare to no dust test experiment. This clearly shows that solar PV module with no dust addition gives the highest efficiency during operation as reviewed in previous works.

The summary of the 3 W solar PV panel for all test conditions in terms of performance ratio is presented in Fig. 5; since solar PV modules do not produce the same power as rated by the company. Thus, the performance ratio becomes the best platform for comparison, defined in equation (3) [17]:

$$\text{Performance ratio} = \frac{GP_{max}}{EP_{rated}} \quad (3)$$

where G is the standard solar irradiance of 1000 W/m^2 and E retain its definition as in equation (2). It can be observed that the performance ratio decreases for each tested condition. Also, a substantial progress in the performance ratio was experimental when there is no dust addition on solar PV module. This indicates that the PV module performed better under no dust test condition.

Fig.5. Dust samples performance ratio for the 3 W polycrystalline solar PV panel.

4. CONCLUSION

[In this paper, elemental composition of dust particles and influence of dust addition on a 3 W polycrystalline solar PV module was probed under 470 W/m^2, 715 W/m^2 and 756 W/m^2 solar irradiations. The research was conducted in an outside condition under natural sunlight. The influence of ash, cement, rice husk, brick dust and sand samples on the maximum power, efficiency and performance ratio of the solar PV module were individually investigated. The fraction weight composition of elements found per dust sample obtained from EDX analysis show that silicon has the largest content followed by aluminum, carbon, calcium and potash. The obtained results specified a decline in output power, efficiency and performance ratio, when dust particles were added on the tested solar PV module. The power reduction, efficiency and performance ratio depends on the dust and its density; hence the density for each tested sample was constant. From the result, the highest calculated efficiency was observed to occur at 756 W/m^2 for all the tested dust samples. Brick dust was found to record the highest maximum power of 1.58 W at 756 W/m^2 with efficiency of 14.51 % and performance ratio of 0.70 whereas cement due to its high percentage weight of carbon, offer the lowest reduction of 1.06 W with efficiency 9.74% and performance ratio of 0.47. Nevertheless, under greater solar irradiance, the influence of dust was observed to reduce slightly but not negligible. Thus, in practice dust must be removed from the surface of solar PV module in order to ensure utmost performance.

Finally, these dust samples have been taken for the present study in Makurdi; because solar is growing exponentially. Besides, there are many places which have to be covered in future such as construction sites, agricultural land and many more. Consequently, it is recommended that installed PV modules be cleaned routinely as dust particles hid on the solar panel naturally.

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REFERENCES

1. Kumar, N. M., Gupta, R. P., Mathew, M., Jayakumar, A., & Singh, N. K. (2019). Performance, energy loss, and degradation prediction of roofintegrated crystalline solar PV system installed in Northern India. *Case Studies in Thermal Engineering*.2019;(*13)*100409.Available: https://doi.org/10.1016/j.csite.2019.100409
2. Hussain, A., Batra, A., & Pachauri, R. An experimental study on effect of dust on power loss in solar photovoltaic module. *Renewables: Wind, Water, and Solar*. 2017; *4*(1). Available: https://doi.org/10.1186/s40807-017-0043-y
3. Andrea, Y., Pogrebnaya, T., & Kichonge, B. Effect of Industrial Dust Deposition on Photovoltaic Module Performance: Experimental Measurements in the Tropical Region. *International Journal of Photoenergy*,*2019*.Available:https://doi.org/10.1155/2019/1892148
4. Al-Hasan, A. Y. A new correlation for direct beam solar radiation received by photovoltaic panel with sand dust accumulated on its surface. *Solar Energy*. 1998; *63*(5), 323–333. https://doi.org/10.1016/S0038-092X(98)00060-7
5. Ekici, S., & Kopru, M. A. (2017). Investigation of PV system cable losses. *International Journal of Renewable Energy Research*. 2017; *7*(2), 807–815.
6. Chanchangi, Y. N., Ghosh, A., Sundaram, S., & Mallick, T. K.. Dust and PV Performance in Nigeria: A review. *Renewable and Sustainable Energy Reviews*. 2020; *121*(January), 109704. Available: https://doi.org/10.1016/j.rser.2020.109704
7. Hammad, B., Al-Abed, M., Al-Ghandoor, A., Al-Sardeah, A., & Al-Bashir, A. Modeling and analysis of dust and temperature effects on photovoltaic systems' performance and optimal cleaning frequency: Jordan case study. *Renewable and Sustainable Energy Reviews*. 2017;(*82)* 2218–2234. Available: https://doi.org/10.1016/j.rser.2017.08.070

8. Costa, S. C. S., Diniz, A. S. A. C., & Kazmerski, L. L. Solar energy dust and soiling R&D progress: Literature review update for 2016. *Renewable and Sustainable Energy Reviews*. 2018; *82*(September), 2504–2536. Available: https://doi.org/10.1016/j.rser.2017.09.015
9. Rahman, M. M., Islam, M. A., Karim, A. H. M. Z., & Ronee, A. H. Effects of Natural Dust on the Performance of PV Panels in Bangladesh. *International Journal of Modern Education and Computer Science*.2012; *4*(10), 26–32. Available: https://doi.org/10.5815/ijmecs.2012.10.04
10. Salim, A. A., & Eugenio, N. N. A comprehensive report on the performance of the longest operating 350 kW concentrator photovoltaic power system. *Solar Cells*. 1990;*29*(1), 1–24. Available: https://doi.org/10.1016/0379-6787(90)90011-S
11. Sulaiman, S. A., Hussain, H. H., Siti, N., Leh, H. N., & Razali, M. S. I. *Effects of Dust on the Performance of PV Panels*.2011; 588–593.
12. Elminir, H. K., Ghitas, A. E., Hamid, R. H., El-Hussainy, F., Beheary, M. M., & Abdel-Moneim, K. M. Effect of dust on the transparent cover of solar collectors. *Energy Conversion and Management*. 2006; *47*(18–19), 3192–3203. Available: https://doi.org/10.1016/j.enconman.2006.02.014
13. Mani, M., & Pillai, R. Impact of dust on solar photovoltaic (PV) performance: Research status, challenges and recommendations. *Renewable and Sustainable Energy Reviews.2010;* *14*(9), 3124–3131. Available: https://doi.org/10.1016/j.rser.2010.07.065
14. Maghami, M. R., Hizam, H., Gomes, C., Radzi, M. A., Rezadad, M. I., & Hajighorbani, S. (2016). Power loss due to soiling on solar panel: A review. *Renewable and Sustainable Energy Reviews*. 2016;(*59*, 1307–1316. Available: https://doi.org/10.1016/j.rser.2016.01.044
15. Rocha, M. P., Rubio, J. E. C., Sidrach-de-Cardona, M., Montiel, D., Sánchez-Friera, P., Carretero Rubio, J. E., & Piliougine Rocha, M. Comparative Analysis of the Dust Losses in Photovoltaic Modules With Different Cover Glasses. *23rd European Photovoltaic Solar Energy Conference*. *September 2008;* 2698–2700. Available: https://doi.org/10.4229/23rdEUPVSEC2008-4CO.1.2
16. Sayyah, A., Horenstein, M. N., & Mazumder, M. K. Energy yield loss caused by dust deposition on photovoltaic panels. *Solar Energy*.2014;(*107)*, 576–604. Available: https://doi.org/10.1016/j.solener.2014.05.030
17. Adinoyi, M. J., & Said, S. A. M. Effect of dust accumulation on the power outputs of solar photovoltaic modules. *Renewable Energy*. 2013; *60*, 633–636. https://doi.org/10.1016/j.renene.2013.06.014
18. Ilse, K. K., Figgis, B. W., Naumann, V., Hagendorf, C., & Bagdahn, J. Fundamentals of soiling processes on photovoltaic modules. *Renewable and Sustainable Energy Reviews*. 2018; (*98)* 239–254. Available: https://doi.org/10.1016/j.rser.2018.09.015
19. Kaldellis, J. K., Fragos, P., & Kapsali, M. Systematic experimental study of the pollution deposition impact on the energy yield of photovoltaic installations. *Renewable Energy*. 2011; *36*(10), 2717–2724. Available: https://doi.org/10.1016/j.renene.2011.03.004
20. Sarver, T., Al-Qaraghuli, A., & Kazmerski, L. L. A comprehensive review of the impact of dust on the use of solar energy: History, investigations, results, literature, and mitigation approaches. *Renewable and Sustainable Energy Reviews*. 2013;(*22)*, 698–733. Available: https://doi.org/10.1016/j.rser.2012.12.065
21. Zeedan, A., Barakeh, A., Al-Fakhroo, K., Touati, F., & Gonzales, A. S. P. Quantification of pv power and economic losses due to soiling in Qatar. *Sustainability (Switzerland)*,.2021;*13*(6), 1–26. Available: https://doi.org/10.3390/su13063364

22. Sayigh, A. A. M. Effect of Dust on Flat Plate Collectors. In *SUN: Mankind's Future Source of Energy*. International Solar Energy Society.1978. Available: https://doi.org/10.1016/b978-1-4832-8407-1.50190-2
23. Baraya, J., Abdullahi, B. H., & Igwenagu, U. S. *The Effect of Humidity and Temperature on the Efficiency of Solar Power Panel Output in Dutsin-Ma Local Government Area (L . G . A), Nigeria EFFICIENCY OF SOLAR POWER PANEL OUTPUT IN DUTSIN-MA*. *2020. Availaibl:* https://doi.org/10.18488/journal.2.2020.101.1.16
24. Kazem, H. A., & Chaichan, M. T. (2016). Experimental analysis of the effect of dust's physical properties on photovoltaic modules in Northern Oman. *Solar Energy*.2016;(*139)* 68–80. Available: https://doi.org/10.1016/j.solener.2016.09.019
25a. El-Shobokshy, M. S., & Hussein, F. M. Degradation of photovoltaic cell performance due to dust deposition on to its surface. *Renewable Energy*. 1993;*3*(6–7), 585–590. Available: https://doi.org/10.1016/0960-1481(93)90064-N
25b. El-Shobokshy, M. S., & Hussein, F. M. (1993b). Effect of dust with different physical properties on the performance of photovoltaic cells. *Solar Energy*. 1993; *51*(6), 505–511. https://doi.org/10.1016/0038-092X(93)90135-B
26. Fountoukis, C., Figgis, B., Ackermann, L., & Ayoub, M. A. Effects of atmospheric dust deposition on solar PV energy production in a desert environment. *Solar Energy*. 2018; (*164*) 94–100. Available: https://doi.org/10.1016/j.solener.2018.02.010
27. Karmouch, R., & Hor, H. EL. Solar Cells Performance Reduction under the Effect of Dust in Jazan Region. *Journal of Fundamentals of Renewable Energy and Applications*.2017; *07*(02), 8–11. Available: https://doi.org/10.4172/2090-4541.1000228
28. Darwish, Z., Kazem, H., Sopian, K., Alghoul, M., & Chaichan, M. Impact of some environmental variables with dust on solar photovoltaic (PV) performance: review and research status. *International J of Energy and Environment*. 2013; *7*(4), 152–159.
29. Rajput, D. S., & Sudhakar, K. Effect of dust on the performance of solar PV panel. *International Journal of ChemTech Research.2013; 5*(2), 1083–1086.
30. Darwish, Z. A., Kazem, H. A., Sopian, K., Al-Goul, M. A., & Alawadhi, H.. Effect of dust pollutant type on photovoltaic performance. *Renewable and Sustainable Energy Reviews*. 2015; (*41):* 735–744. Available: https://doi.org/10.1016/j.rser.2014.08.068
31. Javed, W., Wubulikasimu, Y., Figgis, B., & Guo, B. (2017). Characterization of dust accumulated on photovoltaic panels in Doha, Qatar. *Solar Energy*. 2017; (*142)* 123–135. Available: https://doi.org/10.1016/j.solener.2016.11.053
32. Roy, S. (2014). Impact of carbon dust particle deposition and partial shadow of PV array. *Asia-Pacific Power and Energy Engineering Conference, APPEEC*. *Marc,h* 2014. Available: https://doi.org/10.1109/APPEEC.2014.7066191
33. Said, Syed A.M., & Walwil, H. M. Fundamental studies on dust fouling effects on PV module performance. *Solar Energy*.2014;(*107)*, 328–337. Available: https://doi.org/10.1016/j.solener.2014.05.048
34. Mekhilef, S., Saidur, R., & Kamalisarvestani, M. Effect of dust, humidity and air velocity on efficiency of photovoltaic cells. *Renewable and Sustainable Energy Reviews*. 2012;*16*(5), 2920–2925. Available: https://doi.org/10.1016/j.rser.2012.02.012
35. Sulaiman, S. A., Mat, M. N. H., Guangul, F. M., & Bou-Rabee, M. A. Real-time study on the effect of dust accumulation on performance of solar PV panels in Malaysia. *Proceedings of 2015 International Conference on Electrical and Information Technologies, ICEIT. July, 2015*; 269–274. Available: https://doi.org/10.1109/EITech.2015.7162938

36. Goossens, D., & Van Kerschaever, E. Aeolian dust deposition on photovoltaic solar cells: The effects of wind velocity and airborne dust concentration on cell performance. *Solar Energy*. 1999; *66*(4), 277–289. Available: https://doi.org/10.1016/S0038-092X(99)00028-6
37. Al-Badi, A. H., Malik, A., & Gastli, A. Assessment of renewable energy resources potential in Oman and identification of barrier to their significant utilization. *Renewable and Sustainable Energy Reviews*. 2009; *13*(9), 2734–2739. https://doi.org/10.1016/j.rser.2009.06.010
38. Darwish, Z. A., Sopian, K., & Fudholi, A. Reduced output of photovoltaic modules due to different types of dust particles. *Journal of Cleaner Production*. 2012; *280*, 124317. Available: https://doi.org/10.1016/j.jclepro.2020.124317
39. Mostefaoui, M., Ziane, A., Bouraiou, A., & Khelifi, S. Effect of sand dust accumulation on photovoltaic performance in the Saharan environment: southern Algeria (Adrar). *Environmental Science and Pollution Research.2019; 26*(1), 259–268. Available: https://doi.org/10.1007/s11356-018-3496-7
40. Igwebike-ossi, C. D., & Igwebike-ossi, C. D. *Elemental Analysis of Rice Husk Using Proton- Induced X-Ray Emission (Pixe) Spectrometry*. 2017; *13*(4), 801–811.
41. Hegazy, A. A. Effect of dust accumulation on solar transmittance through glass covers of plate-type collectors. *Renewable Energy*. 2001; *22*(4), 525–540. Available: https://doi.org/10.1016/S0960-1481(00)00093-8