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Impact of dust on solar photovoltaic (PV) performance: Research status, challenges and recommendations

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ABSTRACT

The peaking of most oil reserves and impending climate change are critically driving the adoption of solar photovoltaic's (PV) as a sustainable renewable and eco-friendly alternative. Ongoing material research has yet to find a breakthrough in significantly raising the conversion efficiency of commercial PV modules. The installation of PV systems for optimum yield is primarily dictated by its geographic location (latitude and available solar insolation) and installation design (tilt, orientation and altitude) to maximize solar exposure. However, once these parameters have been addressed appropriately, there are other depending factors that arise in determining the system performance (efficiency and output). Dust is the lesser acknowledged factor that significantly influences the performance of the PV installations.

This paper provides an appraisal on the current status of research in studying the impact of dust on PV system performance and identifies challenges to further pertinent research. A framework to understand the various factors that govern the settling/assimilation of dust and likely mitigation measures have been discussed in this paper.

Contents

1. Introduction

Maturing technology and commercial vigor has rendered photovoltaic (PV) systems with doped silicon as the major conducting element to be manufactured. The inherent material property of this semi-conductor limits the PV system efficiency of the photovoltaic system to within 15–20%. Appropriate installation design (orientation, exposure, sun-tracers) to maximize solar insolation can potentially ensure sustained yield (electricity). However, these are vulnerable to, often overlooked, on-site omnipresent practicalities such as deposition of dust, bird-droppings and water-stains (salts) can significantly degrade the efficiency of solar thermal installations. For PV installations a module efficiency is further reduced by 10–25% due to losses in the inverter, wiring, and module soiling (dust and debris) [1].

Studies related to dust accumulation is critical as a further decrease in the (practical) system efficiency will tend to make PV systems an unattractive alternative energy source, particularly for the larger domestic markets. Current research into characterizing deposition of dust and their impact on PV system performance is limited given the fact that dust deposition is a complex phenomenon and is influenced by diverse site-specific environmental and weather conditions. Dust is a term generally applying to minute solid particles with diameters less than 500 μm. It

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occurs in the atmosphere from various sources such as dust lifted up by wind, pedestrian and vehicular movement, volcanic eruptions, and pollution. In the context of this paper, dust would also refer to the minute pollens (fungi, bacteria and vegetation) and microfibers (from fabrics such as clothes, carpets, linen, etc.) that are omnipresent and easily scattered in the atmosphere and consequently settle as *dust*.

The characteristics of dust settlement on PV systems are dictated by two primary factors that influence each other, viz., the property of dust and the local environment. The local environment comprises site-specific factors influenced by the nature of prevailing (human) activities, built environment characteristics (surface finishes, orientation and height of installation), environmental features (vegetation type) and weather conditions. The property of dust (type – chemical, biological and electrostatic property, size, shape and weight), is as important as its accumulation/aggregation. Likewise, the surface finish of the settling surface (PV) also matters. A *sticky* surface (furry, rough, adhesive residues, electrostatic buildup) is more likely to accumulate dust than a less sticky, smoother one. It is also a well known that dust promotes dust, i.e. with the initial onset of dust, it would tend attract or promote further settlement, i.e. the surface becomes more amenable to dust collection.

Taking into account the effect of gravity, horizontal surfaces usually tend to accumulate more dust than inclined ones. This however is dependent on the prevalent wind movements. Generally a low-speed wind pattern promotes dust settlement while a high-speed wind regime would, on the contrary, dispel dust settlement and have a cleaning. However, the geometry of the PV system in relation to the direction of wind movements can either increase/decrease the prospects of dust settlement at specific locations of the PV system. Dust is likely to settle in regions of low-pressure induced by high-speed wind movements over inclined/vertical surface. The dispersal of dust attributed to wind movements and geometry of PV system depends on the property of dust (weight, size, type).

A framework to understand the various factors that govern the settling/assimilation of dust is illustrated in Fig. 1. It is easy to discern that the phenomenon of dust settlement is extremely complex and challenging to practically handle/comprehend given all the factors that influence dust settlement.

PV installations are generally expected to be designed for optimum yield or output. The factors that determine optimum or maximum yield can be categorized into those that are alterable and those that remain unalterable. The factors that can be altered provide design flexibility to respond to varying installation requirements; the factors that are unalterable need to be accommodated by default. The various alterable and unalterable factors that influence the design, installation and operation (and maintenance) of PV systems is illustrated in Fig. 2.

Numerous papers have attempted to study the phenomenon of dust settlement in the context of solar PV installations. Based on the nature of investigation into the impact of dust on PV system performance the research can be categorized into the two phases – Phase-I comprised research carried out from 1940 to 1990 and primarily looked into solar system characteristics such as tilt angle and glazing on the impact of dust accumulation. Phase-II comprises research following 1990 and represented more comprehensive studies on dust deposition with greater accuracy in experimented investigations.

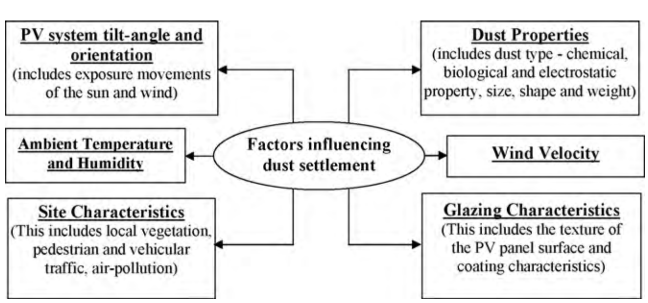

Fig. 1. Factors influencing dust settlement.

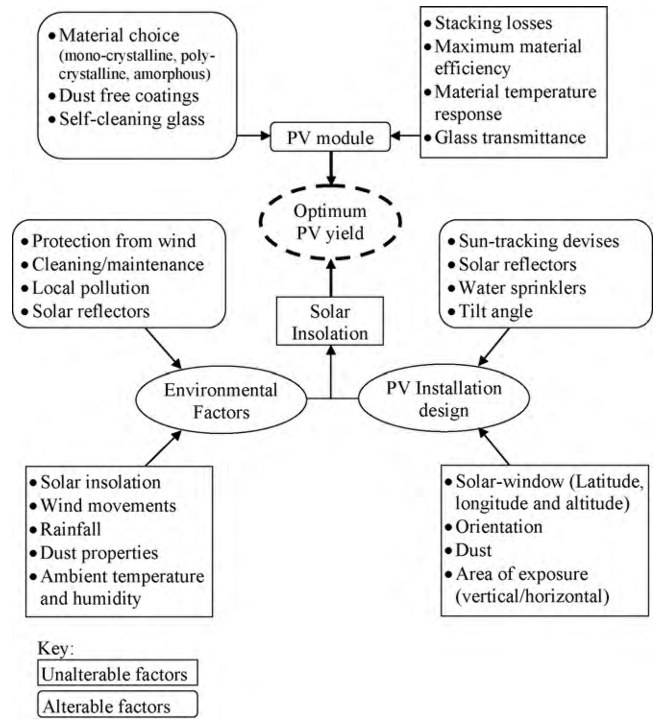

Fig. 2. Alterable and unalterable factors determining maximum PV system yield.

2. Phase-I: 1940–1990

Hottel and Woertz [2] were amongst the pioneers investigating the impact of dust on solar systems. Tests carried out between 9 May to 1 July 1940 on the performance of three sets of solar thermal flat-plate collectors revealed a 1% degradation in collector performance attributed to dust/dirt accumulating on a glass plate inclined at an angle of 30° from horizontal in an industrial area (near a thermal power plant) of the United States of America. The maximum degradation in collector performance was found to be 4.7%, with an average loss in incident solar radiation being less than 1%. A correction factor (0.99 for a glass plate inclined at 45° from the horizontal) was also predicted based on their experimental investigation, which was adopted in the design of flat collectors till the 1970s. Garg [3] subsequently analyzed the influence of dirt on solar transmittance comparing glass plate and plastic films at Roorkee (India). The study concurred with the fact that a horizontal glass receives more dirt than a vertical one, but however recommended a correction factor of 0.92 (as against 0.99 [2]). The transmittance values after a month's exposure for horizontal and vertical glass plate was found to be 30% and 88%, respectively. A significant conclusion from the study revealed only a 8% reduction in transmittance for a 45° tilted glass plate after a month. The correction factor was found unnecessary with daily cleaning of the collector plates. The study also recommended a higher correction factor for plastic films due to their higher electrostatic tendency to attract more dust. Studies by Nimmo and Seid [4] indicate a 26% and 40% degradation in efficiency of thermal panels and photovoltaic cells respectively over 6 months. These results were found to be contentions (and misleading) as they failed to mention characteristics of dust pollution levels during the experimental period.

The study by Salim et al. [5] into long-term dust accumulation on a solar-village PV system near Riyadh (Saudi Arabia) indicated a 32% reduction, after 8 months, in performance of the solar array due to dust accumulation. This was in comparison with an identical PV system tilted at 24.6° that was cleaned daily. On similar lines, a study carried out by Wakim [6] in Kuwait city indicated a reduction in PV power by 17% due to sand accumulation on panels after 6 days. Further, the study also indicated that the influence of dust on PV performance was higher in spring and summer (20% in 6 months) than in autumn and winter.

Sayigh [7] conducted a detailed investigation into effect of dust on solar flat-plate collectors. The experiment comprised seven flat-plate collectors with six arranged in three pairs and subjected to various inclinations of 0°, 30°, and 60°, with the seventh collector inclined vertically at 90°. In each pair one collector was cleaned regularly while the other was kept undisturbed. The amount of absorbed solar energy of the unclean plates was computed and compared to that with the cleaned ones. One of the observations indicated a dust collection of about 2.5 g/m^2/day between April and June. Sayigh et al. [8] also investigated the effect of dust accumulation on tilted glass plates located in Kuwait and found a reduction in plate-transmittance by an amount ranging from 64% to 17% for tilt angles ranging from 0° to 60°, respectively after 38 days of exposure. In addition, a reduction of 30% in useful energy gain was observed by the horizontal collector after 3 days of dust accumulation. The influence of tilt angle on reduction in solar transmittance is illustrated in Fig. 3.

Said [9] studied the effects of several months of dust accumulation in maritime-desert-zone type of environments on solar collectors which included a double-glazed flat-plate collector, an evacuate-tube collector with cylindrical reflectors and a PV panel. A 7% efficiency degradation rate of per month was found for photovoltaic panels, while for thermal panels the degradation rate in optical efficiency ranged from 2.8% to 7% per month.

A study on the impact of dust on the transmittance of various glazing materials conducted by Nahar and Gupta [10] in the desert environment in Thar (India) also concurred with the fact that dust settlement decreases with increase in tilt from the horizontal. The reduction in transmittance for glass was found to be 19.17%, 13.81% and 5.67% for tilt angles 0°, 45° and 90°, respectively. The reduction in transmittance for acrylic was found to be 23%, 13.98% and 8.29% for tilt angles 0°, 45° and 90°, respectively. As revealed by Garg [2], the study also concurred that the accumulation of dust was less on glass than on polyvinylchloride (PVC) and acrylic. The transmittance was severely degraded in the event of a sand/dust storms. A daily cleaning cycle is recommended for desert environments. In addition, the degradation of PVC due to exposure to ultra violet radiation limited its suitability for just 1 year.

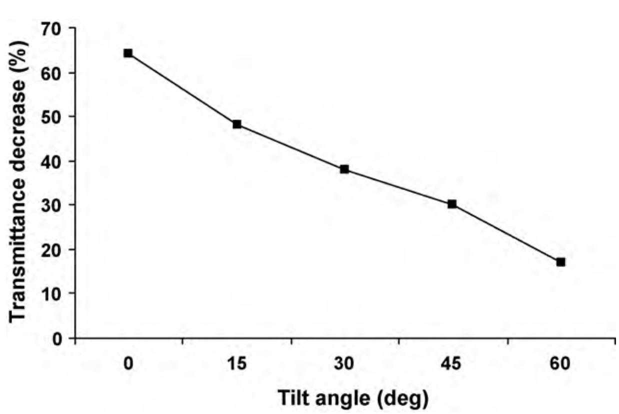

Fig. 3. Graph showing the dependence of light transmittance on the tilt angle [8].

Michalsky [11] and Dietz [12] conducted critical studies into the impact of dust accumulation by using pyranometers solar devices like the pyranometers and validated the reduction in the solar transmittance by 5% over 10 days. Despite instances of rains, less than 1% decrease in this value was observed for unclean pyranometers.

2.1. Critical appraisal on research conducted during Phase-I (1940–1990)

Amongst the consistent critical observations on Phase-I (1940–1990) research into dust accumulation on solar installations (including PV) has been the potential to mislead and/or ambiguity in the experimental methodology and results. The following salient points can be held responsible

- Little study was conducted to assess/monitor the dust (pollution) levels and composition at the location of the solar collector during the course of the experiment/study. With the ambiguity in the dust pollution characteristics, it was possible that the conclusions drawn from an assessment of dust accumulation over a 6 months period is also valid for dust accumulation in 6 weeks in highly polluted sites.
- Most studies had overlooked the influence of prevalent wind movements (speed and direction) and the solar-collector orientation characteristics on their impact on dust accumulation. Both factors critically determine the extent of dust accumulation at any site.
- In few instances it was found that the measurements of the cleaned and the un-cleaned solar systems (under dust accumulation) for transmittance was conducted on different days, further inducing inconsistency in the results drawn from the experimental/study results.
- Very little investigation was conducted on the nature/characteristics of dust itself, viz., type of dust, composition, size (coarse or fine), accumulation rate and fill factor. Dust accumulation characteristics would vary from location from location and hence generalized observations, without investigating dust accumulation characteristics, would have limited applicability.

One of the effective recommendations on mitigating the impact of dust accumulation has been the periodic cleaning of the solar collectors (including PV), and in the event of dust storms immediate cleaning is most effective.

3. Phase-II: 1990 and later

The research (on dust accumulation and its impact on PV performance) subsequent to the 1990s can be characterized by an integrated nature of investigation augmented with sophistication in experimental rigor resulting in greater reliability and accuracy.

El-Shobokshy and Hussein [13,14] are credited as pioneers on a comprehensive study into the impact of dust on the performance of PV cells. The study included investigations into the physical properties of the dust accumulation and deposition density on their impact on parameters degrading PV efficiency. The experiment was entirely simulated with artificial dust (including limestone, cement and carbon particulates) and halogen lamps. While keeping the solar (light) intensity constant and varying the different densities of dust the test was repeated several times. The study revealed the impact of cement particles to be the most significant, with a 73 g/m^2 deposition of cement dust resulting in an 80% drop in PV short-circuit voltage; atmospheric dust with

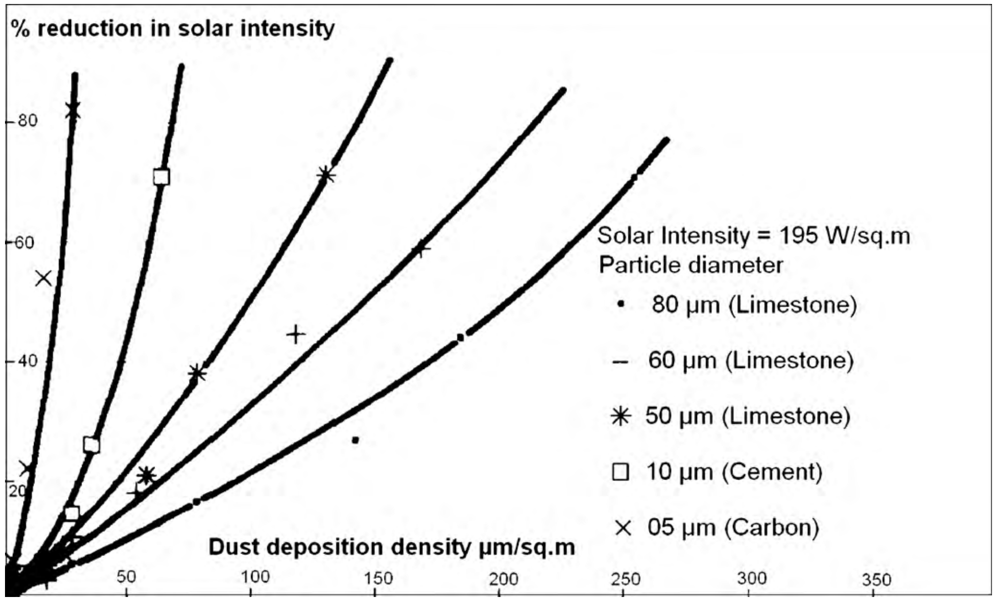

Fig. 4. Solar-intensity reduction in response to dust deposition [13].

mean diameter 80 μm at 250 g/m^2 was found to reduce the short-circuit current by 82%. Fine carbon particulates (5 μm) were found to have the most deteriorating effect on the PV efficiency. The study also found the impact of finer particles to have a greater impact than coarser particles on PV performance (see Fig. 4), for the same dust type. In addition, while the PV fill-factor reduced with excessive dust accumulation, it was found to respond to increase in solar intensity for both cleaned and un-cleaned conditions.

Goossens et al. [15] studied the influence of wind velocity and orientation characteristics of PV system on dust deposition. The study comprised wind tunnel based simulations and experimental field investigations in the Negev Desert for various wind regimes and system orientation. For a PV system (see Fig. 5) inclined at 45° with mirrors (on east and west) the simulation study for the wind sector (SW 10°W–N 10°E), under all wind directions, indicated a general increase in dust deposition with increase in wind speed. However, the deposition of dust relative to the ground (elevation) decreases with increased wind speeds. A noteworthy observation has been the high dust deposition in the afternoon and evening for strong westerly winds, while for southwesterly winds a high dust deposition for found for the evenings alone; for the southwesterly winds little difference was noticed in dust deposition between noon and afternoon. A summary of salient observations has been illustrated in Table 1. The field experiments revealed largest amount of dust settled on PV panels with least deposition on the western mirror during long-term isotropic periods. Under the influence of dust storms, by day the largest amount of dust settled on the PV panels while by night, the largest amount of dust settled on the eastern mirrors.

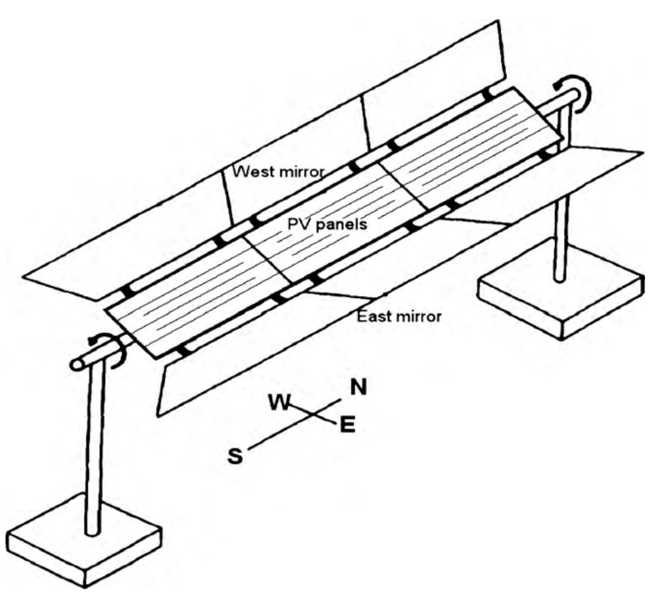

Fig. 5. Experimental PV setup investigating dust deposition under various wind regimes [15].

Among the first of its kind, Al-Hasan [16] mathematically investigated the effect of sand dust deposition on the transmittance of light beam on a PV module. The study effectively formulated equations relating the normal and different incidence angles to the beam transmittance and also a general equation for direct beam radiation received by a tilted surface for greater accuracy and increased predictive capability. The validity proved adequate for reductions in light transmittance up to 50%. The study also investigated the impact of varying dust deposition on the reflectance of light corresponding to its wavelength (see Fig. 6).

Mastekbayeva and Kumar [17] specifically investigated the impact of dust on the transmittance of low density polyethylene (LDPE) glazing and arrived at a dust-corrector factor based on the tilt (inclination) and the number of days of exposure (to dust) in tropical conditions. A 11% reduction in transmittance was estimated for a 5 g/m^2 dust deposition over a month (under natural conditions), for a plastic cover in tropical humid conditions; maximum summer dust accumulation being 3.7 g/m^2 for a month. For a 0.2 mm UV stabilized polyethylene sheet inclined at 15° from horizontal at Bangkok (Thailand), the dust-corrector factor (experimental dust prepared from Bangkok clay – 53–75 μm) for a monthly exposure was by

$$DC_{15} = 0.0001N^2 - 0.0082N + 0.999; \quad 0 \le N \le 30 \text{ for which } R^2 = 0.9963,$$

where DC_{15} indicates the dust-correction factor for a tilt angle of 15° and N stands for the number of days of exposure.

In a more rigorous experiment to characterize the effect of the dust accumulation on glass transmittance, Hegazy [18] conducted a year-long experiment for the subtropical climatic region of Minia

Table 1
Summary: salient observations on dust deposition for various wind directions [15].

Wind direction	Dust deposition trend		
	Minimum	Maximum	Progressive decrease/increase
North	Morning	Noon	Decrease during evening
North-west	Mid morning	Noon	Decrease during afternoon
West	Forenoon (for high velocity winds)	Afternoon	Decrease during evening
South-west	Morning	Afternoon	Decrease during evening

(central Egypt). The experiment comprised nine square glass plates each with 3 mm thickness and an exposed surface area of 0.09 m^2. One plate was kept clean (as the reference plate) while the others were mounted on flat wooden frames facing south and having different inclinations (0°, 10°, 20°, 30°, 40°, 50°, 60° and 90°) to study the extent of dust collection over a month. Following a nonlinear regression on the experimental data an expression relating the dust deposition (ω in g/m^2) to the glass transmittance reduction $(1 - \tau/\tau_{\text{clean}})$, for 1 month period was arrived at as follows:

$$\frac{1-\tau}{\tau_{\text{clean}}}(\%) = 34.37\,\text{erf}(0.17\omega^{0.8473})$$

where $\text{erf}^{-1}(x)$ is the Gauss error function.

The study also revealed that for tilt angles less than 30° the dust deposition (and therefore the decrease in transmittance) is largely site climate-specific. The developed empirical correlation was accurate to ±6% and allowed for calculation transmittance reduction in glass transmittance for a given tilt angle and exposure (days) to the atmosphere. Results from the study could be effectively used along the belts of the Atlantic Ocean to the Persian Gulf for smaller tilt angles, with a recommendation of a weekly cleaning cycle for places exposed to moderate dust levels and an immediate cleaning subsequent to a dust/sand storm.

Hassan et al. [19] studied the effect of airborne dust concentration on PV performance and observed a decrease in efficiency from 33.5% to 65.8% for an exposure of 1–6 months, respectively. It was evident from the study that the degradation progress is dominant and proceeds rapidly during the initial 30 days of exposure (to dust).

The experimental investigation conducted by Eliminir et al. [20] at the National Research Institute of Astronomy and Geophysics (Cairo, Egypt) comprised 100 glass plates with different tilt and azimuth angles. The glass transmittance was evaluated at regular intervals over a 7-month period for the prevalent wind conditions, including thunderstorms. The study revealed a reduction in dust deposition from 15.84 g/m^2 (for a 0° tilt) to 4.48 g/m^2 (for a 90° tilt) and a corresponding increase in transmittance from 12.33% to 52.54%. A governing equation between the dust deposition and

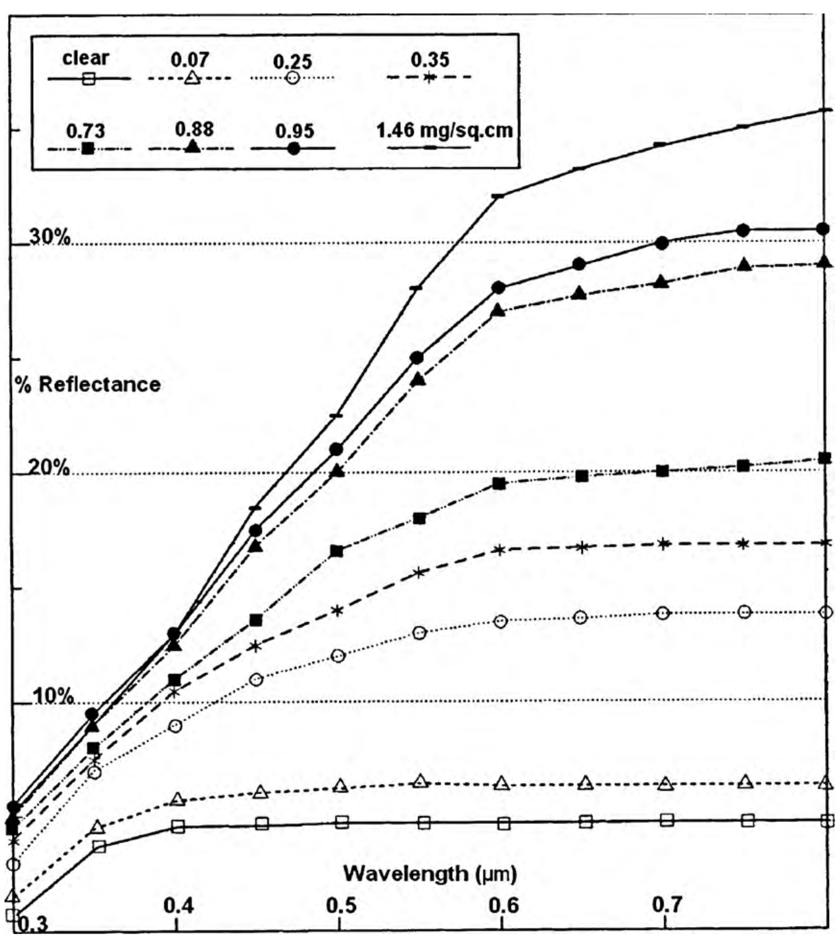

Fig. 6. Impact of dust on the reflectance of glass for various wavelengths [16].

Table 2
General recommendation of mitigation measures against (likely) impact of dust accumulation on PV performance.

Climatic zone and characteristics[a]	Conditions influencing PV performance and dust deposition	Recommended cleaning cycle to mitigate impact of dust
Group-I: Low latitudes – comprise mainly the wet, wet–dry and the dry tropical climate		
Wet tropical Average temperature: 20–34 °C Annual precipitation: >250 cm Latitude range: 10°S to 25°N	Low latitudes require low tilt in PV systems for maximum solar gain, but lower tilts will tend to accumulate higher dust deposition	High annual precipitation could reduce dust accumulation (by periodic washing)
	Tilts higher than latitude recommended to reduce dust accumulation	Weekly cleaning recommended during dry spells and may be altered based on intensity of dust accumulation
	High annual precipitation could minimize dust accumulation	
Wet–dry tropical Temperature range: 20–30 °C Annual precipitation: >150 cm Latitude range: 15° to 25° N and S	Trade winds dominate during the dry season; blow from the north-east in the northern hemisphere and vice-versa	Weekly cleaning recommend for moderate dust accumulation; daily cleaning recommended in case of intense dust accumulation
	PV systems with higher tilt recommended PV panels to be oriented to benefit from the cleaning effect of prevalent winds	
Dry tropical Temperature range: 20–49 °C Annual precipitation: 15 cm Latitude range: 15° to 25° N and S	Regions prone to dusty desert environments and frequent dust storms (for any PV configuration)	Cleaning to respond to intensity of dust accumulation–minimum weekly cleaning recommended
	Low humidity and rainfall Availability of intense solar radiation – PV system may be optimized to maximize harnessing solar energy	Immediate cleaning subsequent to dust storms Adoption/application of dust-repelling coatings may be looked into
Group–II: Mid-latitude climate – comprise mainly the steppe, the Mediterranean, the grasslands and the moist continental climate		
Steppe climate Temperature range: −4 to 40 °C Annual precipitation: less than 10 cm in dry regions to 50 cm in moist steppes Latitude range: 35° to 55° N	High latitudes require high tilt in PV system; a lower fixed tilt angle is recommended to optimize year-round solar gain	With an arid climate with little rains and high tilt angle a moderate cleaning cycle (weekly) could be adequate
	Dust generally tends to fall off with the increase in the tilt angle	With lower tilt angle (to maximize solar gain) a more frequent cleaning cycle (depending on dust intensity) might be beneficial.
Mediterranean climate Temperature range: 10–40 °C Annual precipitation: 42 cm Latitude range: 30° to 50° N and S	High latitudes require high tilt in PV system; a lower fixed tilt angle is recommended to optimize year-round solar gain	Cleaning is recommended once in a week or 2 weeks depending upon the rate of dust accumulation on the surface.
	Dust generally tends to fall off with the increase in the tilt angle	Regions with higher dust accumulation (proximity to industries) a daily cleaning may be beneficial.
Grassland climate Temperature range: −4 to 22 °C Annual precipitation: 81 cm Latitude range: 30° to 55° N and S	High latitudes require high tilt in PV system; a lower fixed tilt angle is recommended to optimize year-round solar gain	A less intense (weekly or biweekly) cleaning cycle might be adequate
	Dust generally tends to fall off with the increase in the tilt angle	Regions prone to higher dust (due to human activities) might require weekly cleaning
	Higher precipitation would aid in cleaning the PV panels	
Group–III: High latitude climate – comprises mainly the taiga and the tundra type of climate		
Taiga climate Temperature range: −22 to 16 °C Average annual precipitation: 31 cm Latitude range: 50° to 70° N and S	High latitudes (close to vertical) require high tilt in PV system; sun tracking mechanism may be required to effectively harness solar energy	Weekly cleaning cycle should be adequate
	Lower ambient temperature improves PV performance	Clearing of snow accumulation needs to be addressed immediately (more frequently)
	Dust generally tends to fall off at near-vertical tilt angle Dust a less critical factor in comparison to maximizing solar gain	
Tundra climate Temperature range: −22 to 6 °C Average annual precipitation: 20 cm Latitude range: 60° to 75° N	High latitudes (close to vertical) require high tilt in PV system; sun tracking mechanism may be required to effectively harness solar energy	Weekly cleaning is recommended, and adjusted based on type (fine/coarse) of dust accumulation
	Dust generally tends to fall off at near-vertical tilt angle	Clearing of snow accumulation needs to be addressed immediately (more frequently)
	Lower ambient temperature improves PV performance Susceptibility to fine-dust collection	

[a] Climate data source [23].

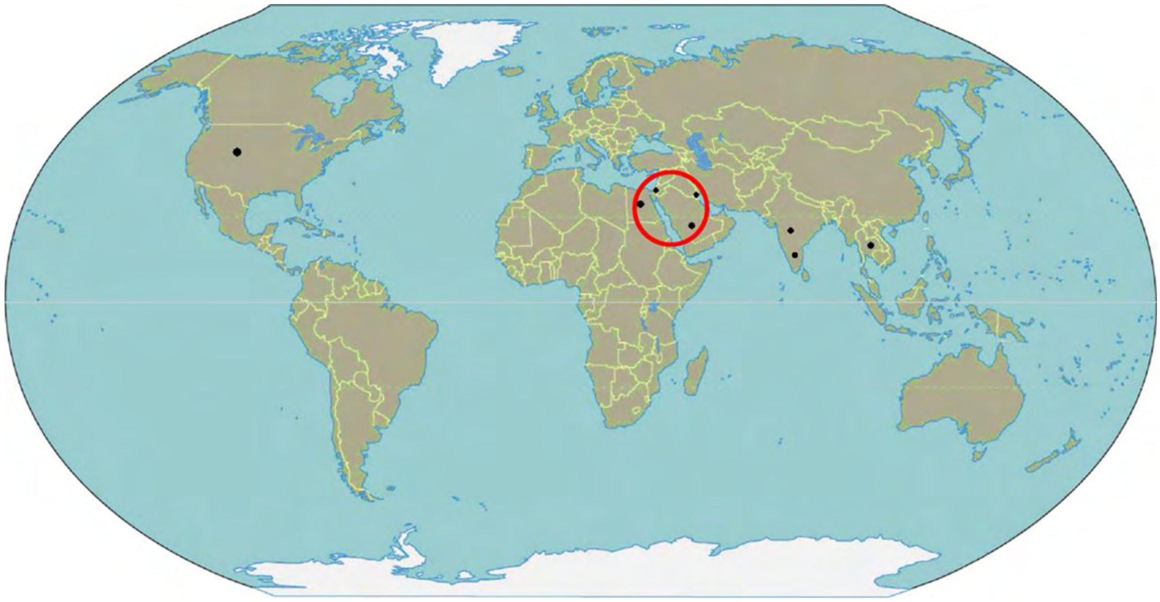

Fig. 7. Geographic distribution of research (impact of dust on solar-collector performance).

reduction in transmittance was also derived. A critical observation revealed that differences in humidity led to the formation of dew on the PV surface which coagulated dust. Weekly cleaning cycle was recommended for moderately dusty places.

A recent performance analysis conducted by Kymakis et al. [21] on a grid connected PV park in Crete attributes the power loss due to soiling (dust deposition) to the type of dust, the length of time since the last rainfall and the cleaning schedule. The analysis, however is based on a much older study [22] and indicates an annual soiling (dust deposition) loss of 5.86%, with the winter losses being 4–5% and 6–7% in summer.

3.1. Critical appraisal on research conducted during Phase-II (1990 and later)

Research conducted during Phaze-II (1990 and later) in investigating the impact of dust on the performance of PV comprised a comparatively (with Phaze-I) deeper study into the various parameters that influence the deposition of dust and the extent of impact. Research thus far has been successful in substantiating the importance of such studies in the effective adoption of PV as a reliable means of harnessing solar energy. However, the following salient limitations still need to be overcome in establishing this research for practical integration in PV system design.

- The properties (optical, size, geometry, electrostatic deposition behavior) of natural dust needs be characterized. Most studies into experimental investigation of dust accumulation have been simulated under artificial dust.
- Studies into biological and electro-chemical properties of dust on their deposition behavior needs to be investigated for various environmental conditions, viz., vegetation type, built environment and climates.
- An optimization study, for various geographical/climatic locations (latitude) considering factor of optimum (fixed) tilt, altitude and orientation for solar gain, prevalent wind patterns and minimum dust accumulation for various PV module configurations would be very valuable.
- Studies based on mathematical models need to incorporate the effect of dust particle geometry on its deposition behavior. Most studies assume the dust particles to comprise perfectly spherical geometry.
- The impact of electrostatic attraction on dust settlement behavior needs to be investigated. Given the nature of PV panels to generate electricity based on electrical-ion generation, they carry the potential to be electrostatic. Dust particles (particularly synthetic fibers) tend to be influenced by electrostatic environments and can result in an increase/decrease in their accumulation.
- Impact of progressive water-stains (scaling) on degrading the PV performance needs to be investigated including appropriate mitigation measures. Dissolved salts in the water used for regular/periodic cleaning of PV modules determine the nature of salt depositing/adhering to the glass surface. Such staining is particularly evident with bird dropping and their subsequent cleaning.

4. General recommendations

The following tables attempt to articulate an approach to evolve appropriate cleaning cycles, for various climatic zones, to mitigate the impact of (likely) dust deposition on PV performance (Table 2).

5. Research: geographic distribution

Interestingly, the concentration of research (thus far) into the impact of dust on the performance of solar collectors (including PV) has been in the middle-east (see Fig. 7). This can be attributed to the immense solar potential (averaging nearly 6 $kWh/m^2/day$ [1]) in these regions combined with the susceptibility to a desert environment (and frequent dust storms).

6. Conclusions

This paper reviews the current state of research into the impact of dust deposition on the performance of solar systems, particularly PV and also identifies challenges to further research in this area. The appraisal on the status of research has been discussed in two phases, Phase-I appraising the research from the 1960s till the 1990; Phase-II appraising the post 1990s research in this area. Based on the exhaustive literature study a recommendation table has been developed to guide in the identifying appropriate cleaning/maintenance cycle for PV systems in response to the prevalent climatic and environmental conditions.

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