Innovative and Sustainable Approach to Clean Solar Panel and Increase Solar Energy Generation

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Abstract

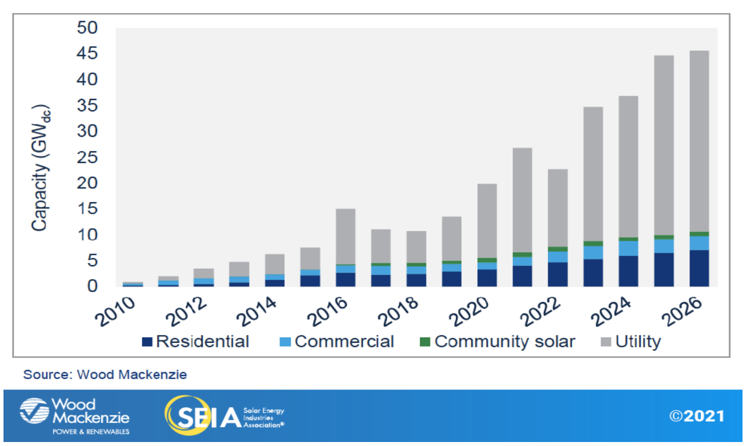
Renewable energy growth is expected to rise as concerns about climate change grow and the demand for cleaner energy sources accelerates. Solar energy alone accounts for over half of all renewable energy produced globally. Solar energy is generated primarily in desert areas due to high solar irradiance. In arid regions, dust can significantly impair energy yield and increase the operational and maintenance costs of solar energy harvesting devices such as Photovoltaics (PV) and Concentrating Solar Power (CSP). Traditional mechanical cleaning methods of PVs and CSPs are time-consuming and labor-intensive processes. They require the use of potable water, a trained workforce, and/or capital-intensive robots. Electrodynamic Shield (EDS) technology offers efficient waterless dust removal through electrodes deposited on the surface of the solar energy harvesting devices. This brief will provide an overview of EDS and put forward a policy recommendation to improve sustainable solar energy generation.

Introduction

Globally, the solar PV systems market is growing at an enormous pace. According to SEIA (Solar Energy Industries Association), the U.S. solar market installed 5.4 gigawatts (GW_{dc}) of solar PV capacity in Q3 2021. Furthermore, as shown in Figure 1, it is expected that over 35 GW of PV capacity will be installed annually over the next 4 years. Across all market segments, solar PV accounted for 54% of all new electricity generating capacity additions in the first three quarters of 2021. Utility-scale PV maintained the largest share of installed capacity in the U.S. solar market as 3.8 GW of utility PV capacity was installed in Q3 2021. A total of 6.1 GW_{dc} of new utility-scale solar power purchase agreements were signed in Q3 2021, bringing the contracted pipeline to 81 GW_{dc} [1, 2]

Large-scale utility solar power plants are usually installed in areas of the highest solar intensity, which often include desert regions. However, desert region installations tend to have a high rate of dust deposition, which results in dramatic losses in power output. Existing literature reveals that multiple factors are responsible for dust deposition on CSP and PV installations [3]. More specifically two major factors play a role: types of dust and geographical location [4]. For example, in such geographic locations as India, China, and the Middle East, very high levels of dust result in a 17-25% reduction in solar panel output [5]. Depending on climate conditions, this reduction can be even more significant, as indicated in a study focused on Egyptian solar installations. In this study, the power output from soiled solar panels was reduced by more than 50% as compared to that from a clean reference panel [6].

Figure 1. US PV installation historical data and forecast 2010-2026



Source: Solar Energy Industry Association

Traditional Cleaning Methods

The existing methods employed for cleaning PV systems include mechanical and coating-based cleaning approaches. In general, mechanical cleaning is based on using brushes to remove surface contamination. As shown in Figures 2 and 3, this approach requires either a trained workforce and/or the use of robots [7-9]. As a result, mechanical cleaning can be viewed as a costly, time-consuming, and labor-intensive solution [10, 11]. Moreover, brushing can create micro-scratches and result in significant PV performance deterioration over time [12]. The extent of micro-scratches depends on brushing trajectory, frequency of cleaning, presence of water and detergents, and type of brushes used for cleaning [13].

Other mechanical cleaning approaches include dry cleaning based on air-blowing [14] and ultrasonic vibrations. The air blowing and vibration methods have not been adopted on a large scale, as their efficiency has not been adequately verified beyond the lab-scale prototypes. Another example of a published mechanical cleaning approach is based on the use of a piezoceramic actuator for removing Martian soil from the PV module [15]. The actuator is shown to wipe the dust from the PV module using forward and backward wiping actions [16].

In contrast to mechanical cleaning, a coating-based approach involves the deposition of super-hydrophilic and super-hydrophobic thin films on the surfaces of PV modules as depicted in Figure 4. Super-hydrophilic films improve surface wettability, causing water to spread on the surface and collect surface layer dust [17, 18]. However, this approach still requires water to remove the remaining dust from the surface of the solar panel. On the other hand, super-hydrophobic films decrease the surface wettability, which then causes water droplets to roll and carry the dust away from the surface [19, 20]. Therefore, the super-hydrophobic coatings also require water to remove dust. Another issue is these coatings are commonly spray-on coatings that need to be frequently reapplied as they degrade over time. Overall, the coating-based approaches have limited efficiency and are not trivial to implement in the large utility-scale solar power plants installed in desert-like regions.

Promising Waterless Cleaning Technology

The emerging waterless cleaning approach, also known as an electrodynamic shield (EDS), utilizes an electric field to remove dust particles from the surface of PV and CSP installations. The scientific basis for this technology rests on interactions between charged dust particles and the electric field to repel the particles from the surface. In general, EDS consists of conducting electrodes insulated from one another and connected to a power supply, which creates an electric field around the electrodes. The concept of the electrostatic curtain for dust particle removal was first developed in 1967 by F.B. Tatom and collaborators at NASA [21]. The technique was further developed in the 1970s by Masuda at the University of Tokyo [22-24]. The first demonstration of this technology for dust removal from solar panels was based on a NASA prototype containing parallel electrodes connected to a single-phase AC power supply [25]. This concept was extended to prevent Martian dust deposition on solar panels, where the screen of conducting electrodes was incorporated into solar panels using parallel patterns [26-33]. The work done by NASA culminated in the effort to develop EDS technology for CSP collectors on Earth in 2014 [34, 35]. The recent work of EDS applied to PV and CSP surfaces show promising results that this technology can be a major step in solar energy production.

Figure 2. Abrasive Manual cleaning using a handheld brush

Source: (Khadka et al 2020, DOI:10.1109/ACCESS.2020.3011553)

Figure 3. Robotic cleaning on solar panels

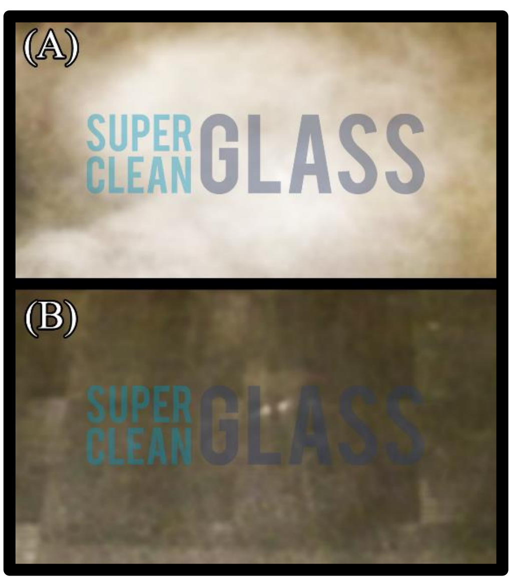
Source: (Khadka et al 2020, DOI:10.1109/ACCESS.2020.3011553)

Figure 4. Hydrophobic coating applied to solar panels

Source: https://www.energy.gov/articles/glass-coating-makes-solar-panels-more-efficient.

Commercial prototypes, such as the example shown in figure 5, have been developed that regains up to 98% of lost energy caused by soiling, while consuming only a fraction of the energy produced by the panels. This technology has the potential to decrease the Levelized Cost of Electricity (LCOE) to USD 0.03 dollars per kilowatt-hour and have a potential Return on Investment (ROI) of 4.3 years according to SuperClean Glass Inc. [36]. Furthermore, according to New York State Pollution Prevention Institute (NYSP2I), SCG's technology has the potential to reduce energy and Greenhouse Gas (GHG) impacts as compared to the baseline by 98.9% and 99.9%, respectively [37].

Figure 5. Commercial prototype EDS. (A) White dust deposited on glass before EDS activation. (B) Glass cleaned after EDS activation



Source: SuperClean Glass

During the last two decades, various computational and experimental evaluations have been undertaken to design optimal electrodes and to identify optimal inter-electrode spacing [38-40]. Further research needs to be carried out to ascertain optimal electrode frequency and voltage application. Research on finding effective electrode configuration for the removal of submicron particles is scant. The current issue in using EDS technology is low removal efficiency for small particles, less than 20 μm in size, as well as persistent dust adhering to the EDS surface due to diurnal cyclic variation in relative humidity. Considering these findings, additional investigation is recommended for achieving higher removal efficiency of submicron dust particles while limiting power consumption. It is recommended that these technological gaps be addressed before deploying this electrostatics-based technology on solar harvesting devices.

Government incentives and funding could further this research and increase its rate of adoption into the market.

Policy Recommendations

Based on our findings, we want to recommend below ideas for sustainable solar energy generation by focusing on the maintenance of solar panels, which is often an overlooked aspect of the solar panel life cycle:

- It is important for policymakers to consider the lifecycle cost of solar farms and the associated environmental impacts. It is prudent that government investment for the installation of new solar farms include proficient funding for environmentally friendly maintenance procedures to decrease the cost and environmental impact of maintenance.
- Government funding is needed for innovative procurement of new cleaning solutions that guarantee the working life of a solar harvesting device to last 25-30 years. These innovations and new solutions can be produced and carried out by small and medium size companies.
- It is important that environmental assessments of solar farms include estimates of Greenhouse Gas (GHG) emissions and the associated societal impact of maintaining and cleaning the solar harvesting devices. These assessments will guide policymakers on which areas need the most funding and support.
- It is advisable to implement tax incentives for utility solar manufacturers to install maintenance systems with low GHG emissions and low negative societal impact on new solar farms.
- It is imperative for policymakers to consider regional economics and labor cost. For example, in

developing countries, manual cleaning using labor is affordable compared to investment in expensive cleaning robots. Therefore, region specific incentives may be provided to implement sustainable cleaning solutions and minimize water waste and environmental impact.

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