PSE Healthy Energy

Comparative Analysis of Environmental Impacts of Utility-Scale and Distributed Solar

Teresa Dayrit

Solar photovoltaic (PV) technology provides the opportunity to generate electricity with very low greenhouse gas (GHG) emissions. Both utility-scale (large solar plant) and distributed (rooftop) systems have been growing in total installed capacity, and decreasing in cost, in the past decade [1]. However, solar PV has energy, GHG, hazardous material, water and land use impacts associated with mining, manufacturing, operational use, and end-of-life. Below, we detail some of these environmental impacts, as well as approaches to minimizing these impacts. We first compare the material and land use impacts of utility versus distributed solar. We next describe the energy and material use associated with manufacturing and end-of-life. Finally, we identify barriers to solar deployment and offer some potential solutions.

I. Distributed v. Utility-Scale Solar

The environmental impacts of distributed solar (e.g. rooftop or community installations) differ from utility-scale PV systems primarily due to differences in capacity factor and in land use.

1. Capacity Factor

The capacity factor of an electricity generation system is the ratio of its actual generation over a period of time to its potential output if operated at full capacity continuously over the same period of time. The capacity factor of solar systems typically depends on the amount of solar irradiation (insolation) that reaches a panel as well as technology differences like use of solar tracking systems. The average capacity factor of distributed PV in the US is about two thirds the capacity factor of utility-scale system due to both higher isolation and the use of tracking system at many utility-scale sites.

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Average 2015 capacity factors in the United States [3, 4]

- Distributed PV: 19.05%
- Utility-scale PV: 30.5%

However, delivered energy decreases for utility-scale PV due to transmission losses, which are typically around 6% [2]. This difference in capacity factor means that in order to produce the same amount of energy, residential solar would require roughly 50% more solar panel area. The environmental impacts of greenhouse gases and material use from solar panel production and manufacturing are therefore approximately 50% higher on average for distributed PV. This assessment does not account for any GHGs associated with land use change, which may vary based on the location of utility-scale solar plants.

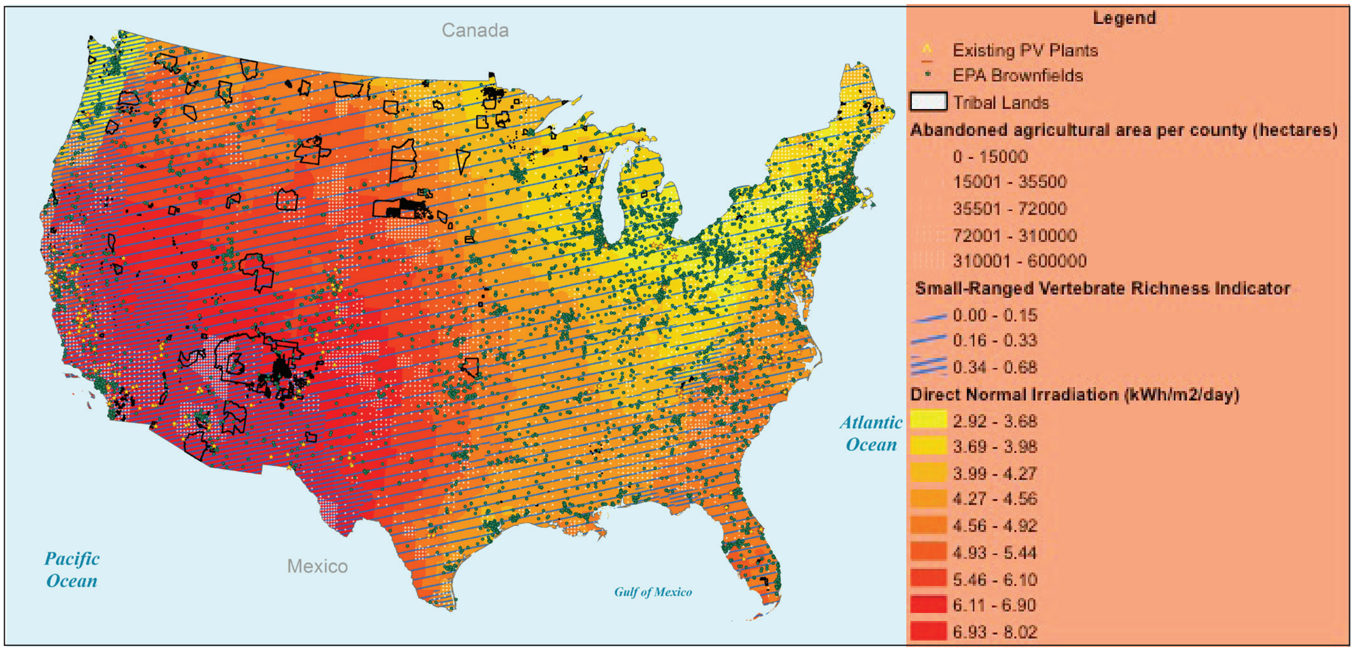

Figure 1. Utility-Scale PV Potential and Land Use in the United States. Existing PV plants, EPA brownfield sites, tribal lands [5], abandoned agricultural area [6], small-ranged species richness indicator [7], and direct normal irradiation [8]. Optimal sites for utility-scale solar will be marginalized land or areas with low biodiversity and high insolation.

2. Land Use

Distributed PV arrays, which are most commonly built on existing homes and buildings, have minimal land use impact. However, utility-scale solar facilities raise concerns about land degradation as well as habitat and ecosystem loss. Land impact from utility-scale solar can be minimized through effective siting on marginalized land: brownfields, abandoned mining lands and croplands, and existing transportation corridors. In addition, in order to maximize use of solar resources as well as limit impact of new transmission, ideal locations for solar farms exist in areas of high insolation and in proximity to existing electrical transmission. A sample of these land use considerations are mapped in **Figure 1**.

Generation from utility-scale and distributed solar, however, may not be directly comparable in terms of their broader impacts on the grid. Based on their location and operation, each installation type may be more likely to displace one type of fossil generation than another. From a utility perspective, distributed solar looks similar to consumers saving electricity; an urban rooftop solar system may reduce generation at a natural gas plant used to meet peak load. A transmission-connected utility-scale PV plant may also reduce peak demand, but is dispatched by utilities and therefore will have comparatively different reductions in GHG emissions based on the electricity mix.

While environmental impacts from material and energy inputs are greater for distributed solar due to a lower capacity factor, utility-scale installations impact land use to a much greater extent.

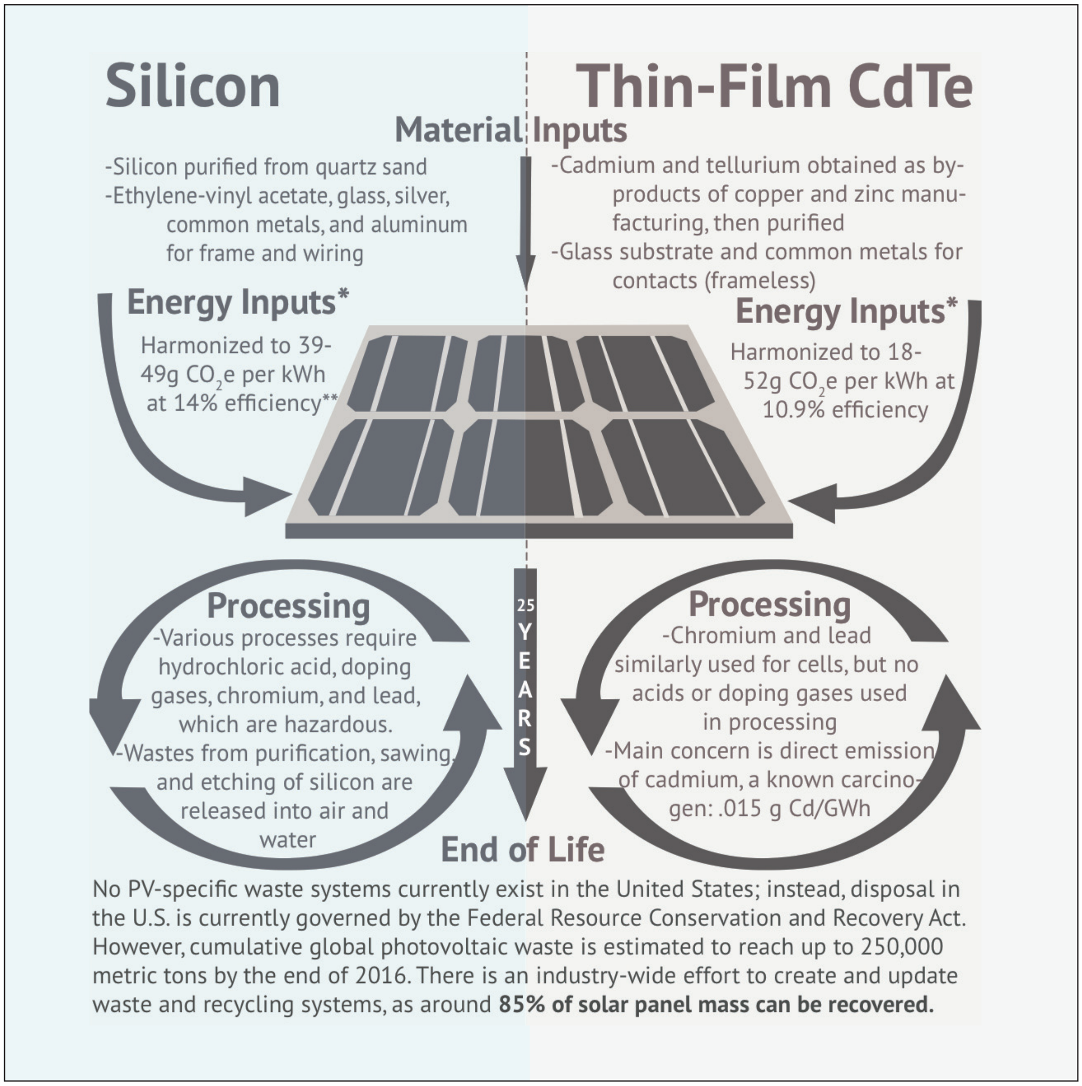

Figure 2. Photovoltaic Material Inputs, Energy Inputs, Processing, and End-of-Life [9-11].
* Associated GHG emissions are reported in carbon dioxide equivalent (CO_2e) over 100 years.
**Harmonization normalizes differences in insolation, performance ratio, and efficiency across 41 and 5 studies for c-silicon [10] and CdTe [11], respectively, reported from 25th to 75th percentile.

II. Environmental Impacts of PV Manufacturing

Although there are low direct emissions from PV system operation, the production of PV panels is associated with GHG emissions, hazardous releases, and water consumption, which could pose serious environmental or public health threats [9]. Energy and material use for two common commercial classes of PV cells—silicon and thin-film cadmium telluride (CdTe)—are shown in **Figure 2.** CO_2e per kWh of energy produced by PV varies based on specific electricity resources used for production. Associated heavy metal emissions include arsenic, cadmium, and lead. End-of-life recycling or disposal presents additional environmental challenges. Although large portions of panel mass can be recovered, not all of this is recycled directly into PV, and much is instead down-cycled into lower-grade materials [12].

In addition, there are several occupational hazards related to the supply chain, mining, manufacturing, siting and installation, and recycling of PV. These include but are not limited to: chemical and heavy metal exposure [13], pyrophoric gas (silane) explosions, illnesses such as Valley Fever resulting from land disturbance, falling, electrocution, and injuries from broken glass.

III. Overcoming Barriers to Deployment

Various factors inhibit the growth of PV deployment. These challenges, along with possible solutions, are outlined below for both utility-scale and distributed solar, indicated by blue and green icons, respectively.

U Utility D Distributed

Barriers to Deployment	Possible Solution
Transmission U Unless utility-scale PV plants are located in proximity to existing transmission lines, new transmission lines must be built in order to bring this electricity to consumers, which results in construction-related emissions and additional land use impacts.	Building utility-scale PV plants in proximity to existing transmission lines will minimize construction emissions and land use impacts, as well as costs.
Siting U Due to the land use and biodiversity concerns of utility-scale PV installations, finding appropriate sites is a challenge. Furthermore, the prioritization of agricultural land limits utility-scale PV deployment in several regions around the U.S. It is important to assess sites carefully before extensive planning; in the past, several planned PV plants have been canceled for ecological reasons, which is financially wasteful and delays progress.	The map in **Figure 1** shows some potential sites for solar farms: brownfields, abandoned agricultural and mining lands, and landfills. These marginalized lands have already been impacted ecologically; utility-scale solar farms will have decreased land use impact.
Grid D When residences install solar systems, a net metering system allows surplus energy flow from the solar panel into the grid to offset the cost of power drawn from it. However, as residential solar continues to grow, the grid will become increasingly unequipped to deal with the energy produced by the consumer— perhaps even to the point of electricity flowing in the wrong direction through substations.	The long-term solution to integrate both solar and other energy technologies is to modernize the power grid and to incorporate smart technologies like smart inverters, which will increase not only the ability to integrate solar, but also provide a suite of other benefits, including greater resilience, efficiency, and flexibility.
Access D Rooftop solar is typically only available for those who own homes and have appropriate roofs; only 22 to 27% of residential rooftop area is suitable for hosting a PV system [14]. This precludes many residents, particularly those of lower socioeconomic status, from receiving the financial benefits of net metering.	Community solar programs and remote net metering are voluntary options for renters, those with shaded roofs, and those who cannot install panels on their roofs due to financial or other reasons, helping to create more equitable access to solar. These installments are larger than residential systems and provide power to multiple members, yet are not run by utility companies.
Cost U D Average levelized cost of solar has dropped to $50 to $70 per MWh for utility-scale PV and $184 to $300 for distributed solar [15], but in some regions remains more expensive than traditional generation from fossil fuels. Furthermore, solar has larger capital costs but lower operational costs than traditional generation, requiring improved financing mechanisms.	Many states offer tax incentives, subsidies, and net metering mechanisms for homeowners who choose to install solar panels. In addition, financing and solar loans are available. PV prices have dropped 50-70% in the past years [1], and ongoing price declines combined with improved finance mechanisms will make solar competitive at even more sites. Fair net metering practices can also improve residential solar affordability.

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