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Tracking the Sun, 2023 Edition

Executive Summary

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Berkeley Lab's annual *Tracking the Sun* report describes pricing and design trends among grid-connected, distributed solar photovoltaic (PV) and paired PV+storage systems in the United States.[1] This narrative summary provides an overview of key trends from the latest edition of the report, based on project-level data for roughly 3.2 million systems installed through year-end 2022, representing more than 80% of all systems installed to-date. For additional information, please refer to the full report and accompanying data resources, all available at http://trackingthesun.lbl.gov.

PV System Characteristics

Characteristics of projects in the data sample help to illustrate trends within the broader U.S. market and provide context for understanding installed price trends. Key technology and market trends based on the full data sample are as follows.

- Residential system sizes have been rising steadily over the past two decades, driven by declining costs and rising module efficiencies (see Figure 1). As of 2022, the median size of new residential installs was 7.2 kW, compared to just 2.4 kW in 2000. As with many elements of the analysis, these results are heavily driven by California, which makes up a large share of the sample, and where residential system sizes are relatively small. Median residential PV system sizes in most states were well above 8 kW in 2022, and in many states were above 9 kW. Non-residential system sizes have followed a more irregular trajectory over time and span a wide size range. The majority of systems are relatively small, with a median size of 25 kW in 2022, but the distribution has a long upper tail.

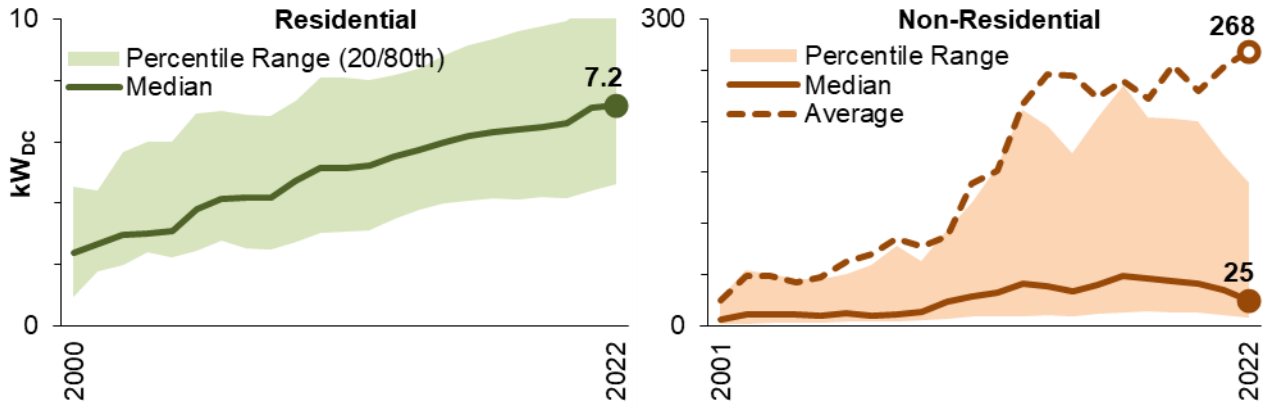

Figure 1. System Size Trends over Time

[1] For the purpose of this report, distributed solar includes residential systems, roof-mounted non-residential systems, and ground-mounted systems up to 5 MW_{AC}. Ground-mounted systems larger than 5 MW_{AC} are covered in Berkeley Lab's companion annual report, *Utility-Scale Solar*.

- Module efficiencies have risen steadily over time: for example, among residential systems, median module efficiencies rose from 13.5% in 2002 (the earliest year with sufficient data) to 20.8% in 2022, with similar rises for non-residential systems as well.
- Module-level power electronics (either microinverters or DC optimizers) have continued to gain share across the sample, representing 93% of residential systems, 83% of small (<100 kW) non-residential systems, and 39% of large (≥100 kW) non-residential systems installed in 2022.
- Inverter-loading ratios (or ILRs, the ratio of module-to-inverter nameplate ratings) have generally grown over time with declining module costs. ILRs have historically been higher for non-residential systems, but rising residential ILRs have closed the gap (a median ILR of 1.22 for residential systems installed in 2022, compared to 1.26 for large non-residential systems)
- Roughly one-third (34%) of all large non-residential systems installed in 2022 are ground-mounted, and 8% have tracking. In comparison, 12% of small non-residential and 1% of residential systems are ground-mounted, and negligible shares have tracking.
- Panel orientation has remained fairly consistent in recent years, with 54% of systems installed in 2022 facing southward (180±45 degrees), 24% to the west, and most of the remainder to the east.
- Third-party ownership (TPO) in the residential sample, which includes both leasing and power purchase agreements, has declined over time from a high of roughly 60% of systems installed in 2012 to 24% in 2021. For the non-residential sample, TPO shares have remained comparatively steady and have historically been lower for small vs. large non-residential systems (14% vs. 32% in 2022). In general, TPO shares tend to be higher in states with richer incentives.
- For-profit commercial customers make up the largest share (>75%) of non-residential site hosts, with the remainder consisting of some combination of tax-exempt customers (schools, government, non-profits). As to be expected, TPO is considerably more prevalent among tax-exempt site hosts than for commercial hosts (38% vs. 16% in 2022).

Paired PV+Storage System Characteristics

The report also describes trends for paired PV+storage systems, including details on battery storage attachment rates (the percentage of PV installations each year that include storage) and system sizing.

- Battery storage is increasingly being paired with distributed PV. In 2022, 10% of all new residential PV installations and 7% of all non-residential installations included battery storage (see Figure 2). Hawaii had, by far, the highest residential attachment rates in 2022 (96%), while attachment rates in California were 11%, and most other states had attachment rates of 5-10%.

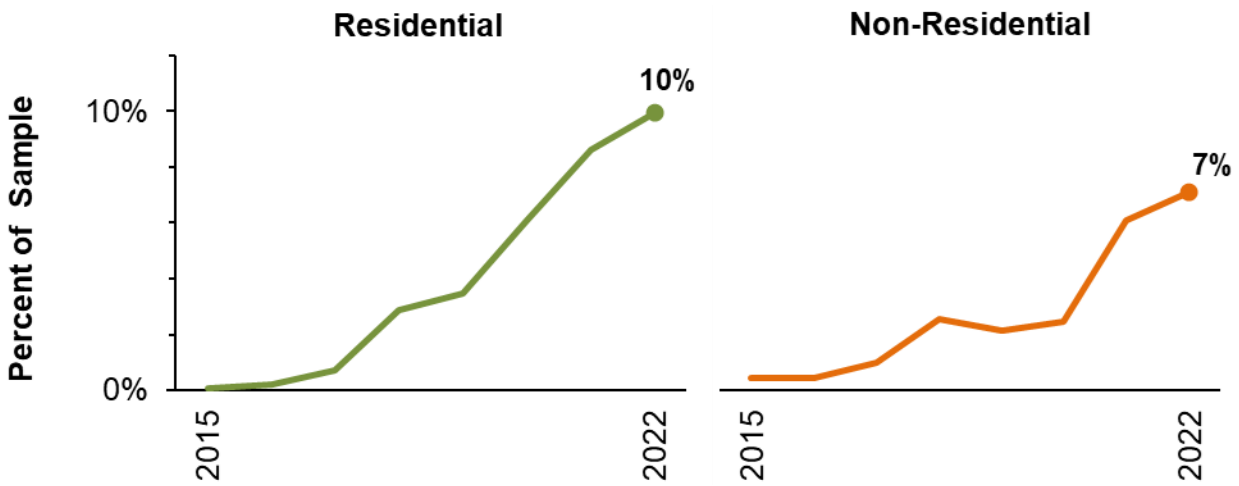

Figure 2. Storage Attachment Rates over Time

- In addition to pairing it with new PV installs, storage is also increasingly being added to pre-existing PV systems. In 2022, 23% of all new paired PV+storage systems in the U.S. consisted of storage retrofits onto existing PV systems. Within the residential market, retrofits are particularly common in California (26% of new paired storage installs in 2022), driven by resilience concerns and TOU pricing. In about half of all cases, storage retrofits are also accompanied by additional PV capacity, on top of the existing PV system.
- The residential market has been trending toward paired systems with larger batteries, driven by backup power demand, though this reversed course slightly in 2022 (35% of paired systems installed in 2022 had 10+ kW of storage)
- In contrast, paired non-residential systems are getting smaller, as uptake expands among smaller customers into applications beyond demand charge management. Of all paired non-residential systems installed in 2022, just over half (51%) had batteries smaller than 10 kW.

Median Installed-Price Trends

The installed price data summarized in the report represent prices paid by system owners prior to receipt of any incentives, and are based on a subset of the larger dataset, consisting of only host-owned systems. These data are self-reported by PV installers or customers and in some cases may include dealer fees for loan-financed systems and other ancillary items related to the PV installation. Prices are also adjusted for inflation, unless otherwise noted.

- Over the long-term, median installed prices for stand-alone PV systems have fallen (in real terms) by roughly $0.4/W per year, on average. However, as shown in Figure 3, price declines tapered off starting in 2013, averaging $0.1-0.2/W per year since then. That tapering off is mostly a function of the underlying trajectory of module costs, which fell precipitously from 2008-2013 before leveling into a more gradual rate of decline. The current installed price trajectory is now primarily driven by changes in balance-of-system and soft costs, which comprise the vast majority of overall system prices. Over the long-term, those BoS+soft costs have, in aggregate, fallen at a relatively steady pace of $0.1-0.2/W per year, on average.

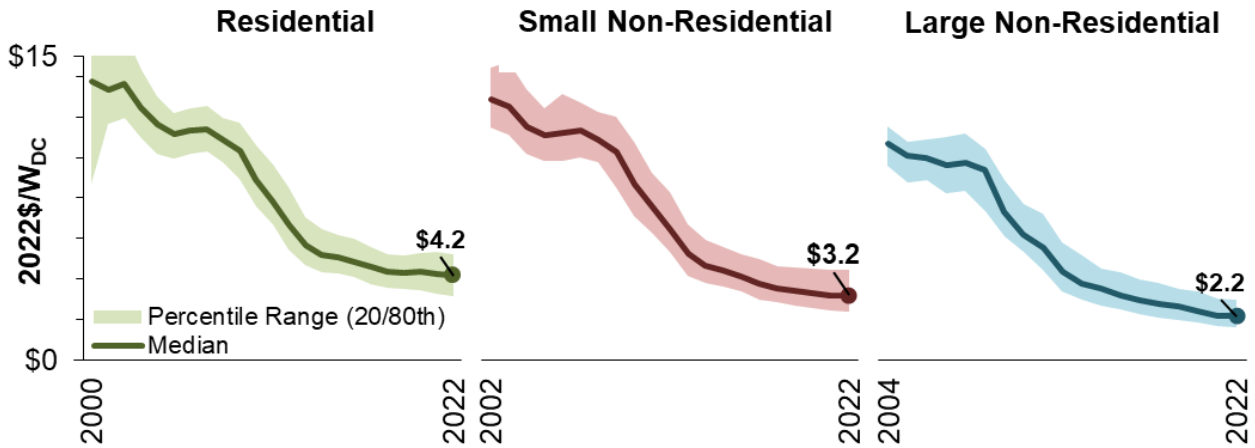

Figure 3. National Installed-Price Trends for Stand-Alone PV

- PV system prices rose in nominal terms over the last two years of the analysis period, but continued to fall in real, inflation-adjusted dollars. From the first quarter of 2021 through the last quarter of 2022, median installed prices for stand-along PV systems rose in nominal dollars by $0.1-0.3/W (or 4-13%), depending on the market segment. For residential and large non-residential systems, the increase in nominal prices was below the rate of inflation, and thus prices in real inflation-adjusted terms fell by roughly $0.2/W in both segments. This is in line with the average rate of real price declines over the past decade.
- National median installed prices from the Tracking the Sun dataset are higher than a number of other common PV pricing benchmarks, which generally align more closely with the 20th percentile levels from Tracking the Sun. These differences reflect a diversity of methods, data sources, and definitions. For example, prices reported for loan-financed systems in the Tracking the Sun dataset may include dealer fees, which other benchmarks typically do not include, and may add upwards of 10-25% to the total up-front price paid by the customer.
- Median installed prices for paired residential PV+storage systems have been declining over time, suggestive of a maturing market (see Figure 4). The price decline is notable given the previously noted trend toward larger residential storage sizing over time. Pricing trends for paired non-residential systems are less clear, though the underlying sample sizes are small.

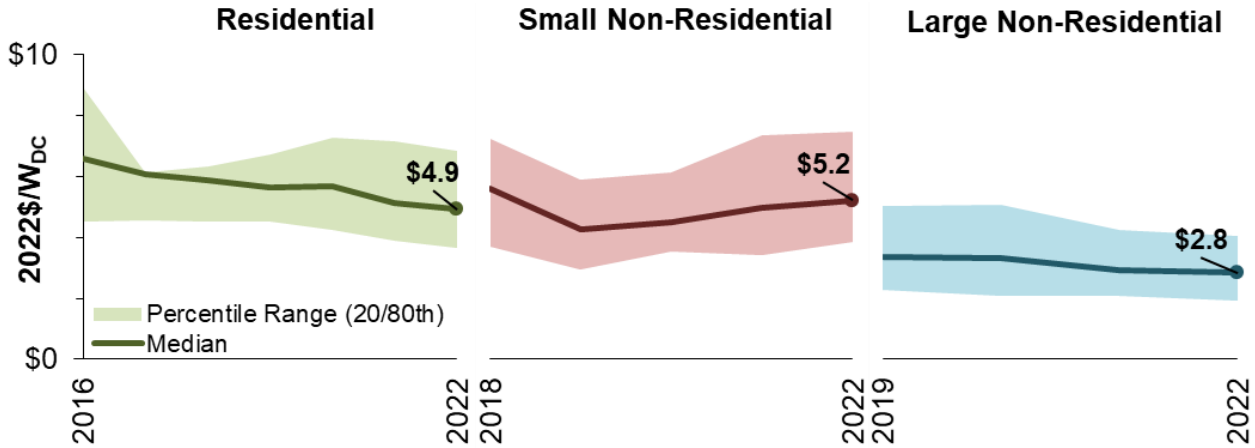

Figure 4. National Installed-Price Trends for Paired PV+Storage

Variation in Installed Prices

While trends in median installed prices can be revealing, the installed pricing data also exhibit substantial variability across projects, as shown in Figure 5 below, reflecting underlying differences in project-level characteristics, installer attributes, and features of the local market, policy, and regulatory environment.

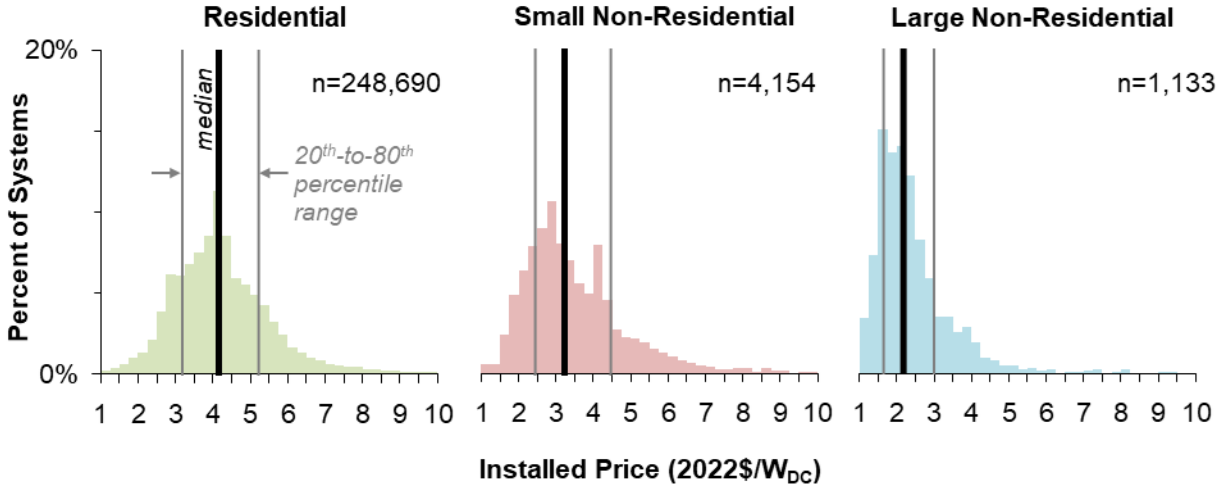

Figure 5. Installed-Price Distributions for Stand-alone PV Systems Installed in 2022

- Installed prices within each customer segment vary substantially depending on system size, with a difference of $1.0/W in median prices between the smallest and largest residential systems, and $2.6/W between the smallest and largest non-residential systems.
- Installed prices vary widely across states, with state-level median prices ranging from $3.1-5.8/W for residential, $2.4-4.4/W for small non-residential, and $1.6-2.5/W for large non-residential systems. A small part of this state level variation can be explained by feature of local PV markets that are modeled as part of the regression analysis, as discussed below.
- Across the top-100 residential installers in 2022 (by volume), installer-level median prices ranged from $2.2-5.7/W, and most had a median price above $4.0/W.
- Within the non-residential sector, installed prices are higher for systems installed at tax-exempt customer sites, compared to prices for commercial site hosts, though this seems to be uniquely the case in California, which represents a large share of the market. Differences were most pronounced for large non-residential systems in California, where tax-exempt customers paid a median price of $3.6/W in 2022, compared to $2.1/W for commercial customers.

The full report also provides descriptive trends comparing median installed prices based on module efficiency and the use of MLPEs, though those pricing differences tend to be relatively small and are more clearly defined through the regression analysis below.

Regression Analysis of Pricing Variability

We apply a multi-variate linear regression model to estimate the effects of individual factors on installed prices, focusing on host-owned residential PV systems installed in 2022, and including both stand-alone PV and paired PV+storage systems. This statistical model includes variables related to system, market, and

installer-level characteristics, as well as state- and quarterly fixed effects variables. Key results from this analysis, as depicted in Figure 6, include the following.

- Of the system-level pricing drivers, battery storage has by far the biggest effect ($1.5/W), followed by new construction systems ($0.6/W less expensive than retrofits).
- Effects associated with the various market- and installer-related drivers are all relatively small (less than $0.2/W), and mostly not statistically significant
- Of particular note is the wide range across the state fixed-effects variables ($1.4/W), suggesting the presence of strong state-level pricing drivers beyond those explicitly captured in the model (e.g., cost-of-living, retail rates, incentives, solar insolation, permitting processes)

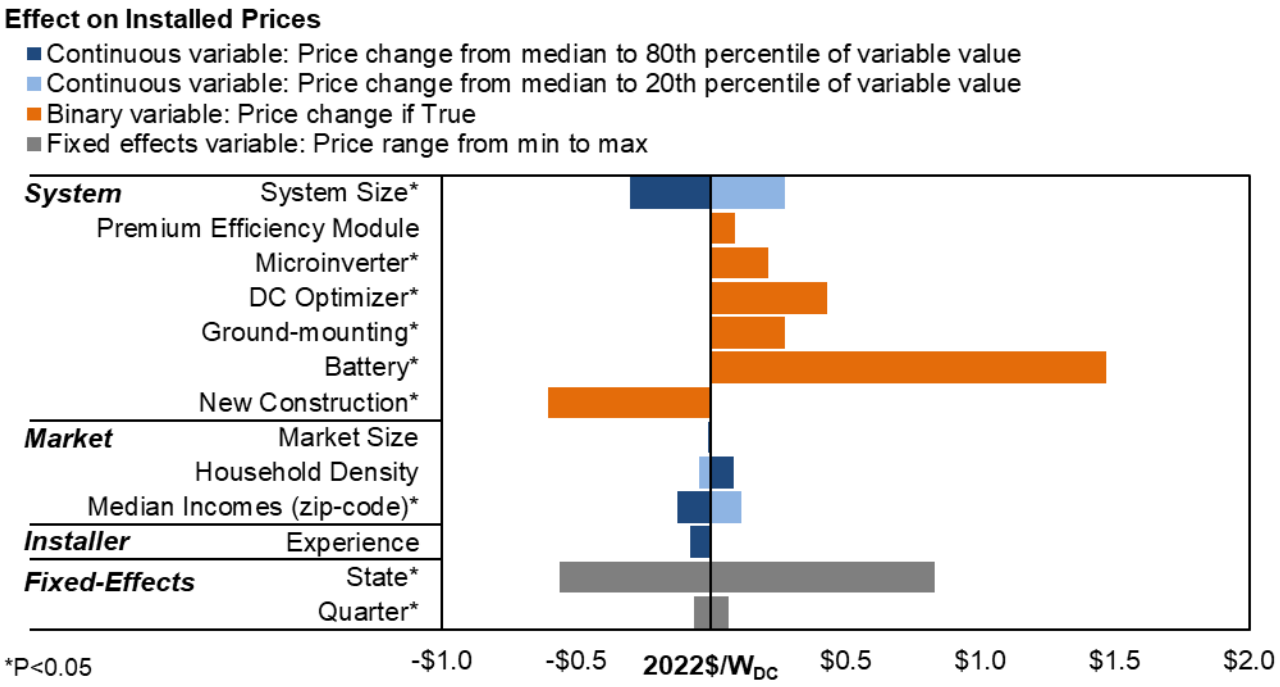

Figure 6. Sensitivity of Installed Prices to Modeled Pricing Drivers

Notes: For continuous variables, the figure shows the effect on system prices associated with moving from the median to the 20th percentile and from the median to the 80th percentile values of those variables. For binary variables, the figure shows the effect if that binary variable is true, and for fixed effects variables, the figure shows the range between the minimum and maximum effect of the variables in each set.

Data Sources and Market Coverage

Trends in the report derive from project-level data provided by state agencies, utilities, and other organizations that administer PV incentive programs, renewable energy credit registration systems, interconnection processes, and net metering programs. Altogether, 70 entities spanning 30 states contributed data to this edition of the report.

The full data sample consists of roughly 3.2 million individual PV systems, representing 81% of all U.S. distributed PV systems installed through 2022, and 73% of systems installed in 2022 (see Figure 7). The analysis of installed prices is based primarily on a subset of the full data sample, consisting of host-owned, stand-alone PV systems, totaling roughly 1.5 million systems installed through 2022. California and several

other large state markets comprise a large share of the sample, as in the overall U.S. market, while smaller state markets tend to be under-represented in the sample.

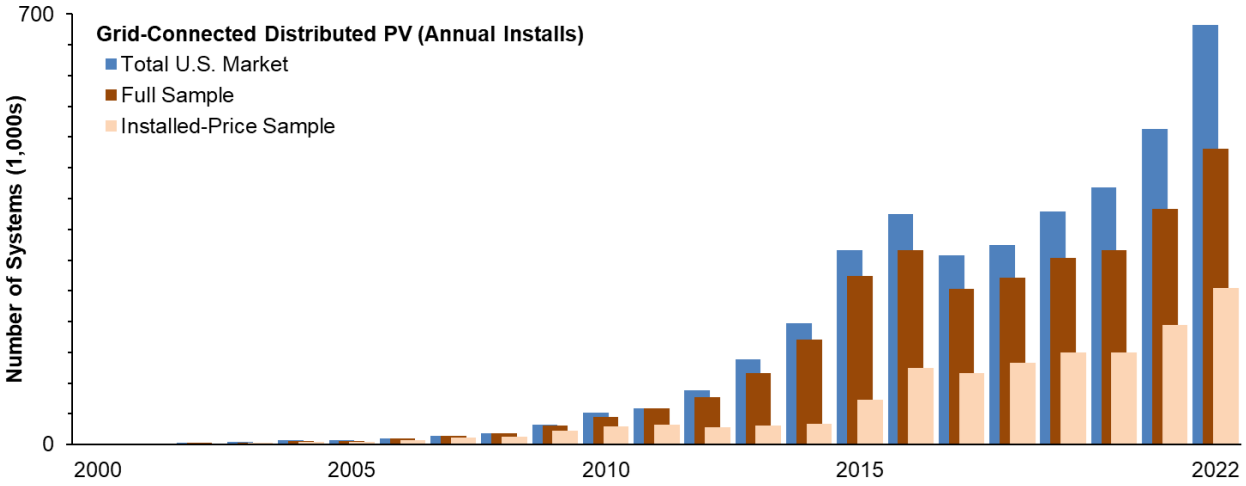

Figure 7. Sample Size Relative to Total U.S. Market

Notes: Total U.S. Market size is based on data from Interstate Renewable Energy Council for all years through 2010 and from Wood Mackenzie and the Solar Energy Industries Association for each year thereafter.

Acknowledgements

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