

August 2024

Tracking the Sun, 2024 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. This narrative summary provides an overview of key trends from the latest edition of the report, based on project-level data for roughly 3.7 million systems installed through year-end 2023, representing roughly 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 2023, the median size of new residential installs was 7.4 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 compared to other states. 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 26 kW in 2023, but the distribution has a long upper tail.
- Module efficiencies have risen steadily over time: for example, among residential systems, median module efficiencies rose from 12.7% in 2002 (the earliest year with sufficient data) to 20.8% in 2023, with similar rises for non-residential systems as well. Increases in module efficiencies since 2010 closely track the rise in residential system sizes, suggesting that module efficiency gains have been a primary driver for growth in residential system sizing.

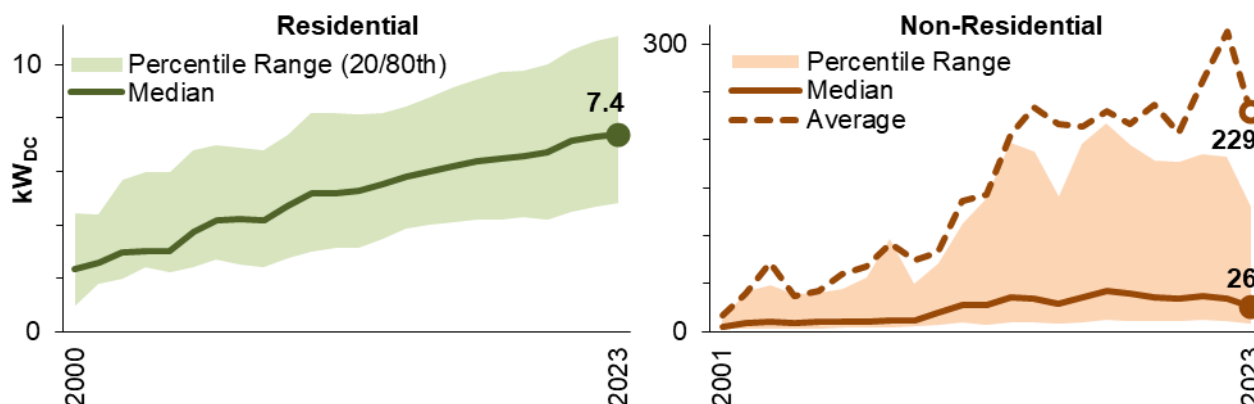


Figure 1. System Size Trends over Time

- Roof-coverage ratios (the percentage of roof-space covered with PV) have been relatively stable over time, and typically range from roughly 15-40% of total roof area for residential systems (with a median of 26% in 2023). For non-residential systems, these values are somewhat lower in the median case, but vary much more widely, reflecting the broader range of building types and configurations.
- Module-level power electronics (either microinverters or DC optimizers) have continued to gain share across the sample, representing 93% of residential systems, 82% of small (<100 kW) non-residential systems, and 38% of large (≥100 kW) non-residential systems installed in 2023.
- Inverter-loading ratios (or ILRs, the ratio of module-to-inverter nameplate ratings) have grown steadily over time for residential and small non-residential systems, but have been fairly flat for large non-residential systems. While ILRs have historically been higher for large non-residential systems, that is no longer the case, as median ILRs were similar across the three sectors in 2023 (1.23 to 1.25).
- Almost one-half (46%) of large non-residential systems installed in 2023 are ground-mounted, and 9% have tracking. In comparison, 16% of small non-residential and 5% of residential systems are ground-mounted, and negligible shares have tracking.
- Panel orientation has remained fairly consistent in recent years, with 56% of systems installed in 2023 facing southward (180±45 degrees), 23% to the west, and most of the remainder to the east.

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, 12% of all new residential PV installations and 8% of all non-residential installations included battery storage (see Figure 2). Hawaii had, by far, the highest residential attachment rates in 2023 (95%), while attachment rates in California were 14%, and most other states had attachment rates of 4-10%.

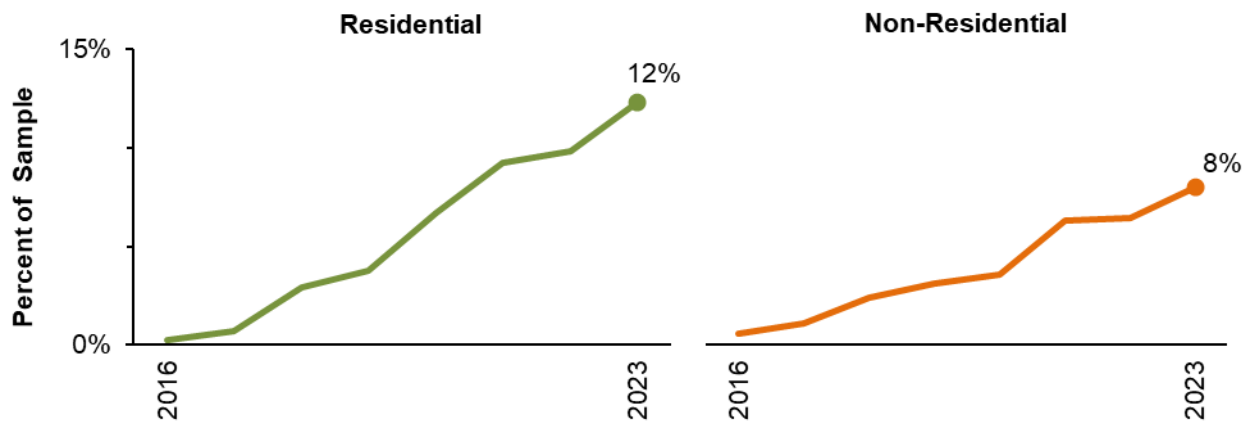


Figure 2. Storage Attachment Rates over Time



- Storage attachment rates in California are rising rapidly as the state transitions from net energy metering to its new net billing tariff structure, which incentivize customers to co-install storage. Though they are still only a small share of the market, roughly 60% of all residential PV installations under the new net billing tariffs are paired with storage.
- The residential market had been trending toward systems with larger amounts of storage capacity, potentially driven by backup power demand, but reversed course the past several years as the market became more geographically diversified. In 2023, 70% of all new paired PV+storage systems included just a single battery with 10-13.5 kWh of energy storage capacity and a 5 kW rated power output.
- 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 2023, just over half (55%) had batteries smaller than 30 kWh.

Third Party Ownership and Customer Segmentation

- 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. Residential TPO shares ticked up slightly to 27% in 2023, potentially because of higher interest rates for solar loans. TPO rates for non-residential systems fluctuate from year to year, and in 2023 were 13% and 33% for small and large non-residential systems, respectively.
- TPO shares at the state level vary substantially, and are generally higher (i.e., residential TPO rates of roughly 40% in 2023) in states with high solar renewable energy certificate prices (DC, MA, NJ) or other lucrative incentive programs (CT, IL).
- Residential systems are overwhelmingly installed on detached single-family homes. By comparison, the non-residential sector is more diverse. In 2023, half of all non-residential installations were installed on commercial properties (including retail, industrial, office, warehouse facilities), roughly one-third on agricultural properties, and 15% by tax-exempt (e.g., government, schools, religious, and other non-profit) customers. As to be expected, TPO rates are substantially higher for tax-exempt site hosts, particularly for schools and government properties, which also tend to have the largest system sizes.

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.

- From 2022 to 2023, median installed prices for stand-alone residential systems fell by roughly \$0.1/W in real (inflation-adjusted) terms, maintaining the same rate of decline as over the past decade. In contrast, median prices for non-residential systems rose for the first time in 15 years, by \$0.1-0.2/W. These small year-over-year changes are sensitive to fluctuations in inflation, and the lagged effect on installed prices, which can vary across projects depending on the length of their development timeline. Looking back over a slightly longer time horizon to the beginning of 2021,

when inflation rates began to rise, installed prices have fallen in real terms across all three customer segments.

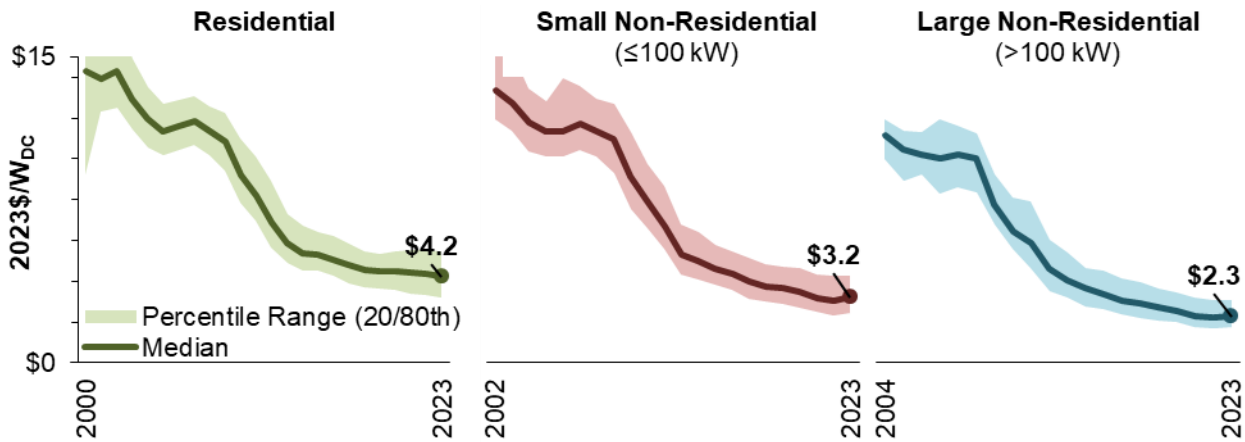


Figure 3. National Installed-Price Trends for Stand-Alone PV

- 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, a large portion of residential systems are loan-financed, and installed prices reported for these systems likely include dealer fees, adding anywhere from 5-50% to the total up-front price paid by the customer (typically not included in other benchmarks).
- Reported prices for paired PV+storage systems have generally been declining over time, despite the fact that reported battery costs (in real, inflation-adjusted terms) have been either flat or rising (see Figure 4). Note that these data come primarily from California’s Self-Generation Incentive Program.

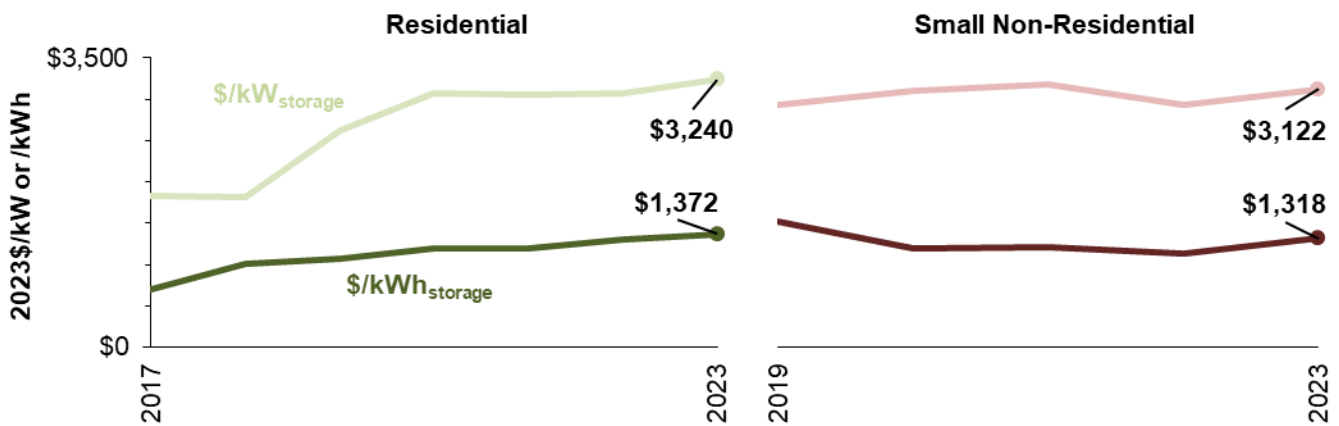


Figure 4. Median Reported Battery Costs in Paired PV+Storage Installations

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.

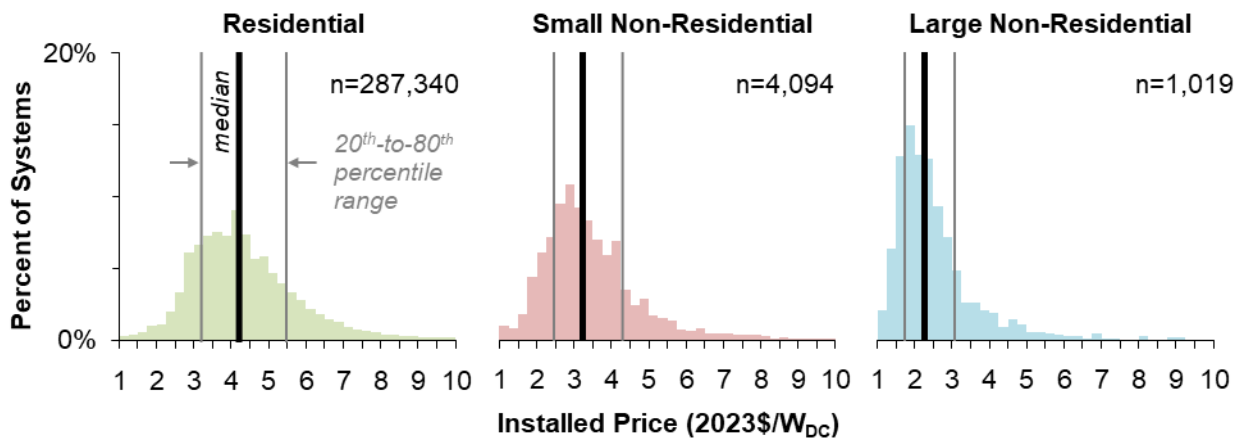


Figure 5. Installed-Price Distributions for Stand-alone PV Systems Installed in 2023

- 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 \$2.2/W between the smallest and largest non-residential systems.
- Installed prices vary widely across states, with state-level median prices ranging from \$3.2-5.2/W for residential, \$2.6-4.1/W for small non-residential, and \$1.8-2.6/W for large non-residential systems. A small part of this state level variation can be explained by features of local PV markets modeled as part of the regression analysis described below.
- Across the top-100 residential installers in 2023 (by volume), installer-level median prices ranged from \$2.6-5.9/W (ignoring several outliers). Roughly one-third of these installers had median prices below \$4/W, while one-third had prices between \$4-5/W, and the remainder had median prices above \$5/W.
- Within the non-residential segment, installed prices tend to be higher for systems installed at tax-exempt customer sites, compared to those installed on commercial and agricultural properties. Differences were most pronounced for large non-residential systems in California, where tax-exempt customers paid a median price of \$4.1/W in 2023, compared to \$2.3/W for commercial customers and \$2.0/W for agricultural customers.

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 2023, and including both stand-alone PV and paired PV+storage systems. This statistical model includes variables related to system, market, installer, and home construction characteristics, as well as state- and quarterly fixed effects variables. Key results from this analysis, as depicted in Figure 6, include the following.

- The largest effects are associated with battery storage (a \$1.4/W increase), new construction (a \$0.7/W decrease), and system size (a \$0.7/W decrease from the 20th to 80th percentile system size). DC optimizers and ground-mounting (uncommon for residential systems) each increased installed prices by \$0.4/W.

- 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 (\$2/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).

Effect on Installed Prices

- Continuous variable: Price change from median to 80th percentile of variable value
- Continuous variable: Price change from median to 20th percentile of variable value
- Binary variable: Price change if True
- Fixed effects variable: Price range from min to max

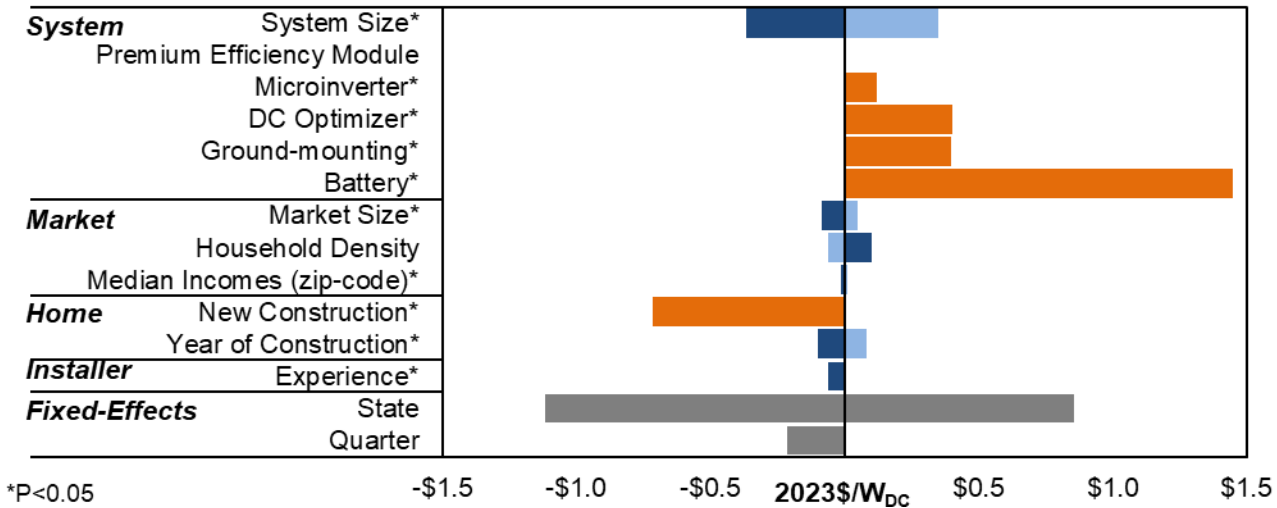


Figure 6. Sensitivity of Residential Installed Prices to Modeled Pricing Drivers

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, 72 entities spanning 31 states contributed data to this edition of the report.

The full data sample consists of roughly 3.7 million individual PV systems, representing 78% of all U.S. distributed PV systems installed through 2023, and 71% of systems installed in 2023 (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 1.7 million systems installed through 2023. 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.

Distributed PV Annual Installs (1,000s)

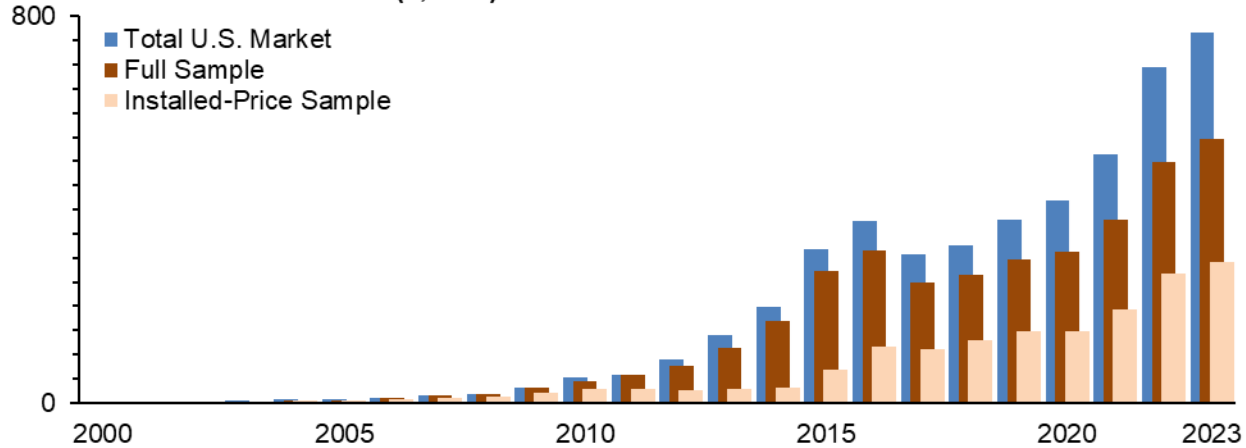


Figure 7. Sample Size Relative to Total U.S. Market

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

This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Solar Energy Technologies Office Award Number 38444. For their support of this project, the authors thank Ammar Qusaibaty, Juan Botero, Michele Boyd, and Becca Jones-Albertus of the U.S. Department of Energy. The authors also thank the many individuals from utilities, state agencies, and other organizations who contributed data to this report and who, in many cases, responded to numerous inquiries and requests. Without the contributions of these individuals and organizations, this report would not be possible.

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