Tracking the Sun

Pricing and Design Trends for Distributed Photovoltaic Systems in the United States

2024 Edition

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Overview

Summarizes installed prices and other characteristics of grid-connected, distributed* solar photovoltaic (PV) and PV+storage systems in the United States

- Current edition focuses on projects installed through 2023
- Describes trends related to:
  - **Project characteristics**, including system size and design, ownership, customer segmentation, and other attributes
  - **Median installed price trends**, both nationally and by state
  - **Variability in pricing** according to system size, state, installer, equipment type, and other factors
- Multi-variate regression estimates the effects of key pricing drivers for residential systems installed in 2023

** For the purpose of this report, distributed systems consist of 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 report, Utility-Scale Solar.*

***New to this edition*:** Trends in roof-coverage ratios and more granular customer segmentation

Accompanying Data Products
available at trackingthesun.lbl.gov

1. **Executive summary:** A short narrative summary of the full slide-deck report
2. **Data visualization tool:** Allows users to create custom figures and explore the full *Tracking the Sun* dataset
3. **Public data file:** The underlying project-level dataset, excluding confidential data

Report Structure

- Data Sources, Methods, and Market Coverage
- PV System Characteristics
- Paired PV+Storage System Characteristics
- Customer Segmentation and Financing
- Median Installed Price Trends
- Variability in Installed Prices
- Multi-Variate Regression Analysis of Residential Installed Prices
- Appendix

Data Sources, Methods, and Market Coverage

Primary Data Sources

Tracking the Sun **relies on** **<u>project-level</u>** **data**

- Provided by state agencies, utilities, and other organizations, for PV systems participating in incentive programs, renewable energy credit registration systems, and interconnection processes
- Some of these data already exist in the public domain (e.g., California's Currently Interconnected Dataset), though LBNL may receive additional data under non-disclosure agreements

72 entities spanning 31 states contributed data to this year's report (see Appendix)

- Some of these are legacy data sources that no longer contribute incremental data each year; incremental data for 2023 come from 45 organizations in 28 states

Supplemental Data Sources

- **BuildZoom* and Ohm Analytics:** PV building permit records used to expand the sample size for trends in customer segmentation, new construction, and battery attachment rates
- **CoreLogic:** Property data used for customer segmentation, to identify PV systems installed on new homes, and to estimate PV roof coverage ratio
- **SEIA/Wood MacKenzie:** Total market size used to benchmark sample coverage, and to calculate average system sizes for states outside the primary data sample

**More information on Building Permit Data provided by BuildZoom is available here: https://www.buildzoom.com/data*

Key Definitions and Conventions

Customer Segments*

- **Residential:** Single-family and, depending on the data provider, may also include multi-family
- **Small Non-Residential:** Non-residential systems ≤100 kW_{DC}
- **Large Non-Residential:** Non-residential systems >100 kW_{DC} (and ≤5,000 kW_{AC} if ground-mounted)

** Independent of ownership structure or whether connected to the customer- or utility-side of the meter*

Units

- Real 2023 dollars (unless otherwise noted)
- Direct-current Watts (W_{DC}), unless otherwise noted

Installed Price: Up-front price (2023$/$W_{DC}$) paid by the PV system owner

- Prior to incentives (i.e., the gross price)
- Inclusive of any up-front loan-financing fees passed through the installer

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Sample Frames and Data Cleaning

Full Sample

Used to describe system characteristics

The basis for the public dataset

1. Remove systems with missing size or install date
2. Standardize installer, module, inverter names
3. Integrate equipment spec sheet data
   – Module efficiency and technology type
   – Inverter power rating
   – Flag microinverters or DC optimizers
4. Convert dollar and kW values to appropriate units, and compute other derived fields

Installed-Price Sample

Used in analysis of installed prices

5. Remove systems if:
   – Missing installed price data
   – Third-party owned (TPO)*
   – Battery storage co-installed
   – Self-installed

Pricing data for paired PV+storage systems presented separately

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** TPO includes both leases and power purchase agreements (PPAs). We exclude TPO systems from the installed-price analysis, as the prices reported for those systems are not strictly comparable to those reported for host-owned systems.*

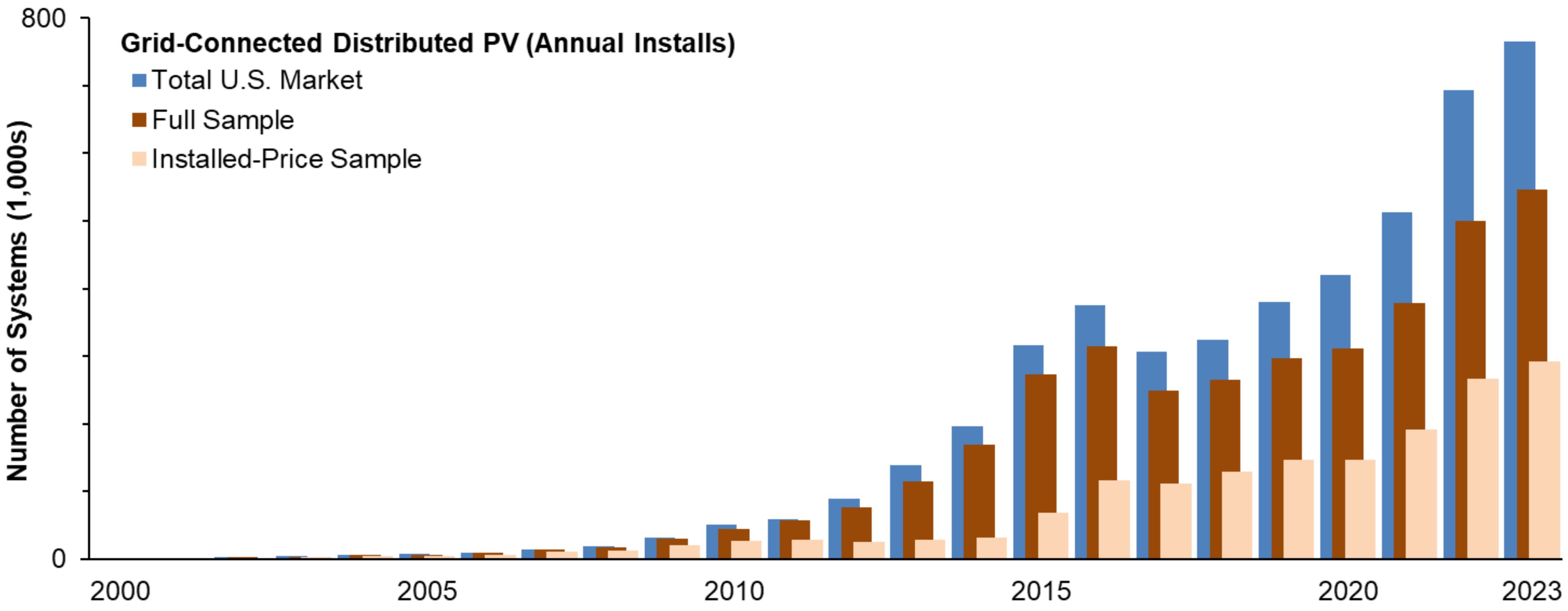
Sample Size Relative to Total U.S. Market

Full Sample

- **3.7 million** systems through 2023 (78% of U.S. market)
- 550,000 systems installed in 2023 (71% of U.S. market)

Installed-Price Sample

- **1.7 million** systems through 2023
- 300,000 systems installed in 2023



Gap between Full Sample and Total U.S. Market: Associated mostly with smaller and mid-sized state markets either missing or under-represented in the sample; see next slide

Gap between Installed-Price Sample and Full Sample: Primarily TPO systems and systems missing installed price data; several states included in the full sample provided no installed price data

Notes: Total U.S. Market size is based on data from Interstate Renewable Energy Council for all years through 2010 and from Wood Mackenzie's annual "Solar Market Insight" report for each year thereafter.

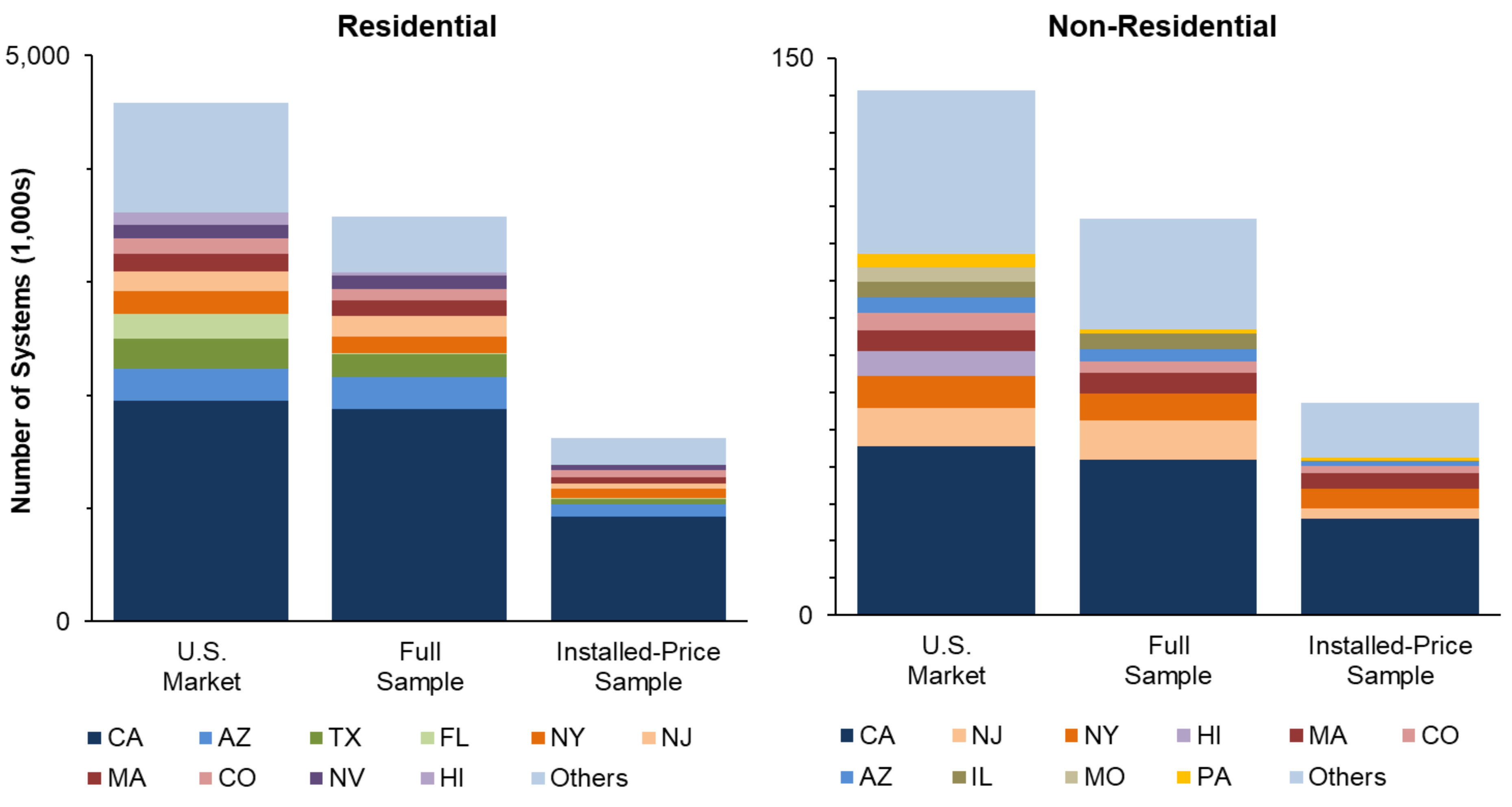
State-Level Sample Distribution and Market Coverage

Sample Distribution: CA dominates the sample, as in the larger U.S. market

Market coverage:

- Similar overall level of market coverage for both residential and non-residential
- In general, coverage among the larger state markets is fairly strong, the main exception being FL
- The most significant gap in the sample is for the collection of smaller state markets (aggregated in the figures as "Others")

Cumulative PV Installs through 2023 (thousands)

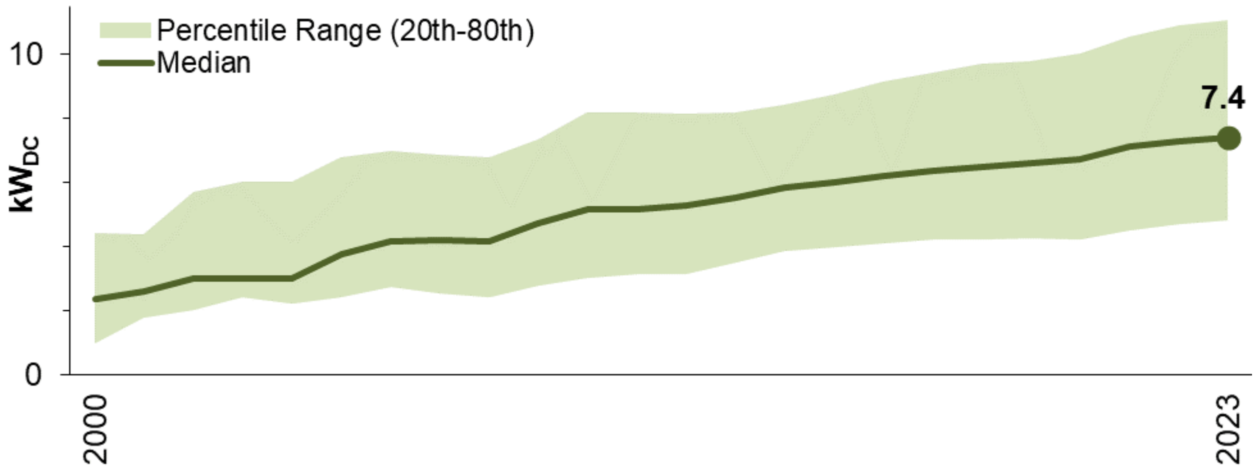


Notes: Data for the total U.S. market are from Wood Mackenzie's 2023 Year-in-Review "Solar Market Insight" report The figures show the top-10 states in each customer segment, based on cumulative U.S. installations through 2023, and all other states are combined in the "Other" category.

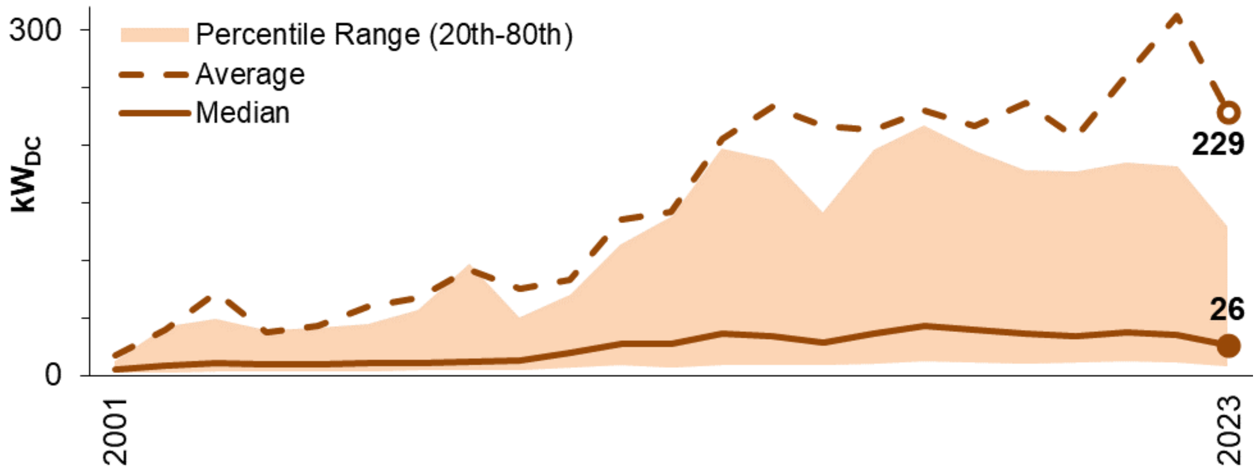
PV System Characteristics

System Size Trends

Residential System Size Time Trends



Non-Residential System Size Trends

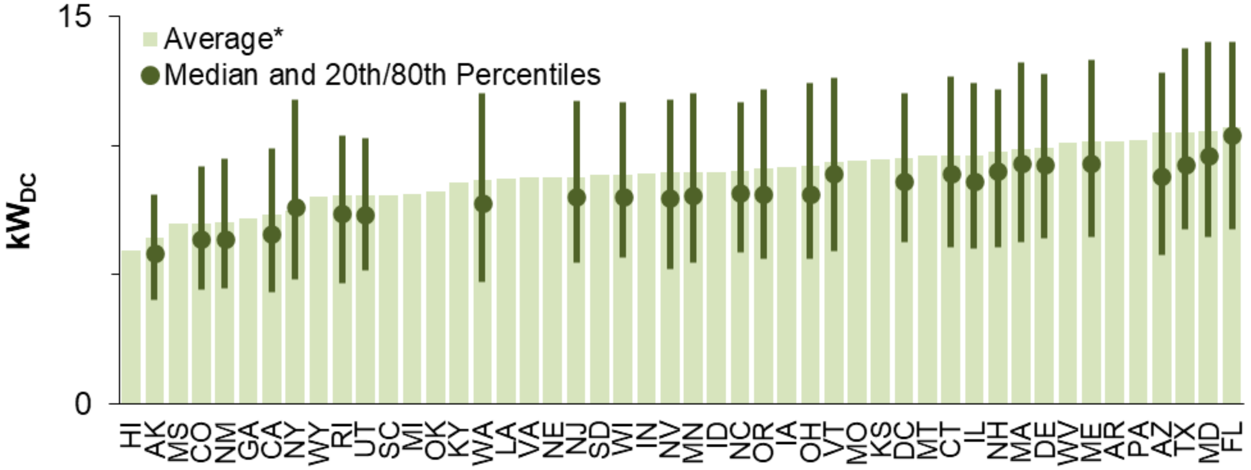


- Residential system sizes have been rising steadily over the past two decades, driven by declining costs and rising module efficiencies, among other factors
- Median residential system sizes reached 7.4 kW in 2023, with most systems ranging from 5-11 kW in size (the 20^{th} to 80^{th} percentile band)
- Non-residential system sizes vary widely, ranging from roughly 10-100 kW between the 20^{th}-80^{th} percentiles, with a median of 26 kW but a long upper tail (229 kW average system size in 2023)
- Historical trends show an abrupt shift toward larger non-residential systems in 2011-14, followed by a plateau, and in recent years some shift back toward smaller sizes (as indicated by the percentile range)

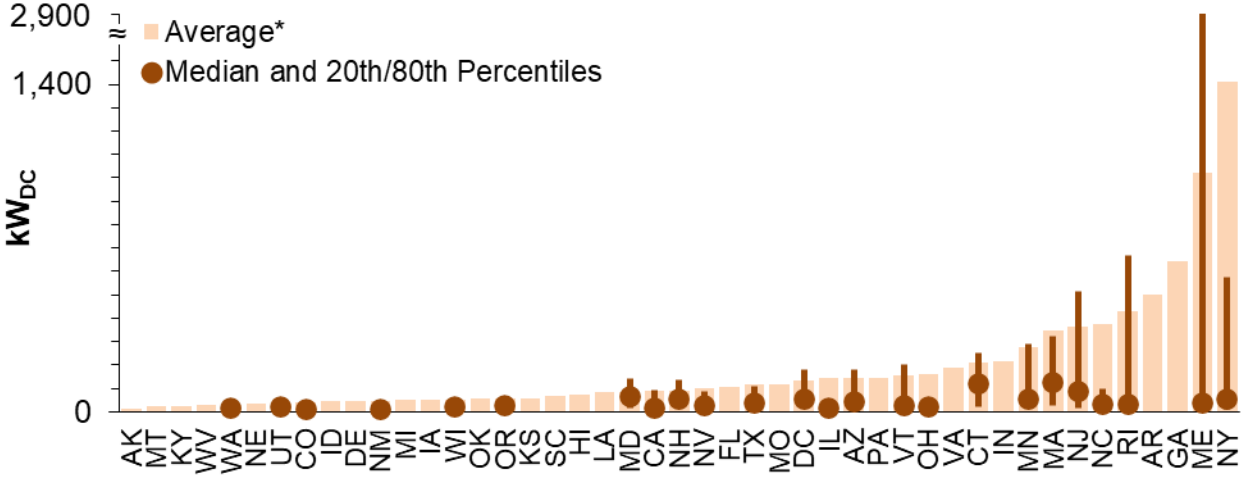
Notes: Summary statistics for any given year are shown only if at least 20 observations are available.

System Size Comparisons by State

Residential System Sizes by State (2023)



Non-Residential System Sizes by State (2023)

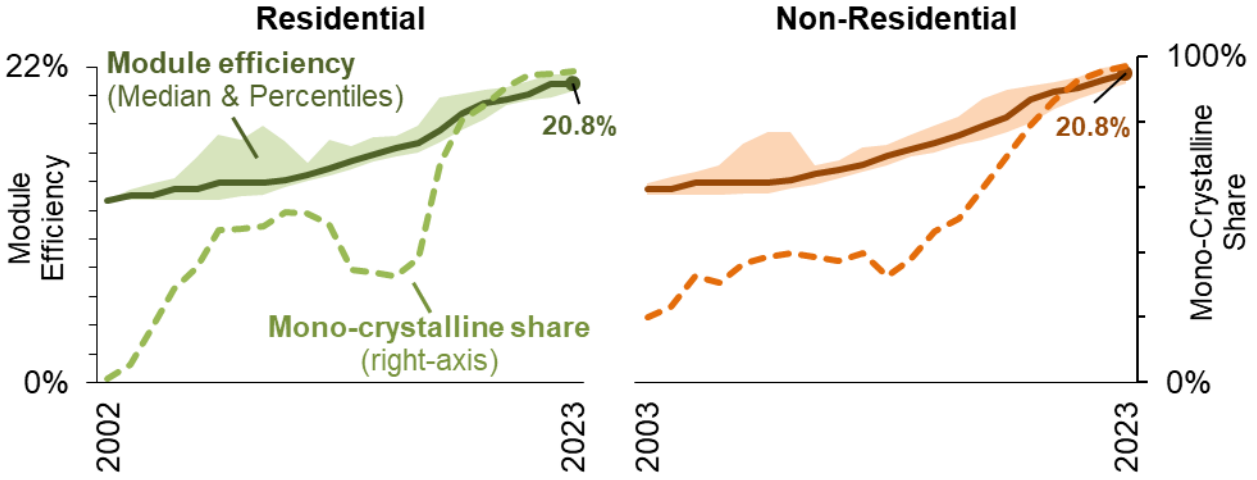


- Residential system sizes vary across states, reflecting regional factors such as electricity usage and insolation levels, among others
  - System sizes in CA (median of 6.6 kW) are near the low end of the spectrum, pulling the U.S. median downward
  - Median sizes in most states are above 7 kW, and in almost half of all states are 8-10 kW
- State-level differences in non-residential sizing are most notable at the upper tail of the distributions and average sizes
  - States on the right-hand side have a significant share of large systems (e.g., community solar projects in ME)
  - In most states, the majority of non-residential systems installed in 2023 were well below 100 kW

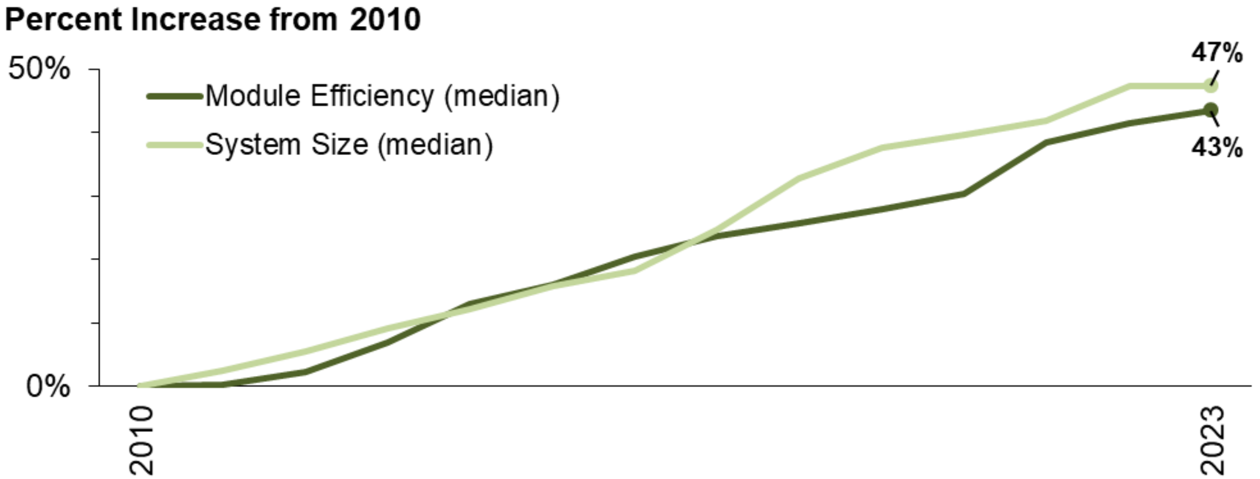
*Notes: *Averages are derived from project level data where available, and in the case of residential systems are calculated from systems <40 kW, in order to exclude erroneous data and to remove large agricultural or multi-family housing projects classified as residential. For states not in the Tracking the Sun dataset, averages are derived from state-level statistics in Wood Mackenzie's annual "Solar Market Insight" report; medians and percentiles are unavailable for those states. Summary statistics for any given state and customer segment are shown only if at least 20 observations are available.*

Module Efficiency Trends

Module Efficiency Trends over Time



Residential Module Efficiency vs. System Sizing

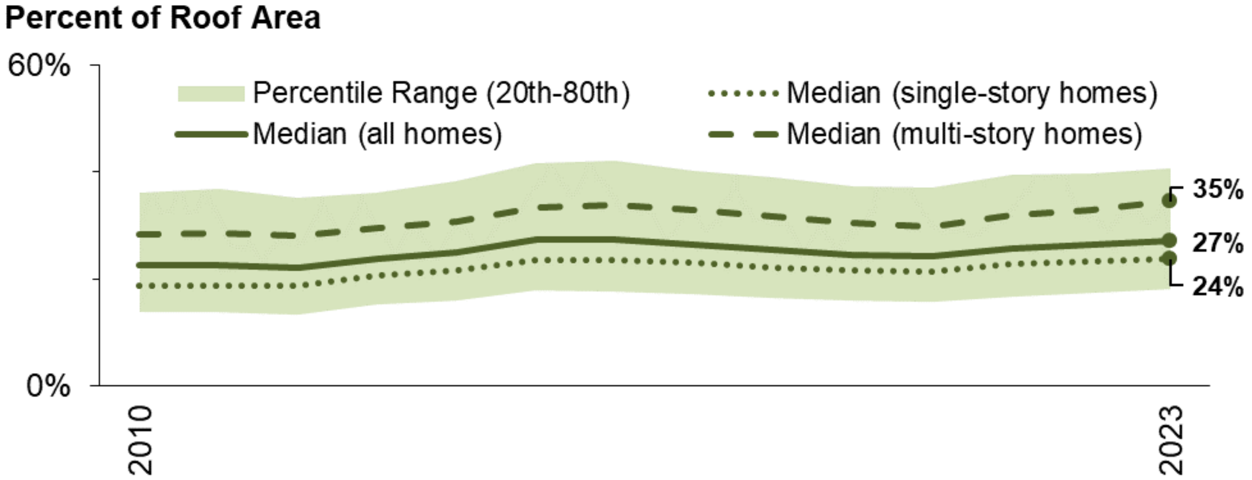


- Module efficiencies have risen steadily over time for both residential and non-residential systems
- Reflects increasing dominance of mono-crystalline modules and continuing innovations in cell architecture (PERC, TOPCon), among other factors
- Higher module efficiencies allow for denser installations, enabling reductions in soft costs and BoS costs that scale with square footage
- Changes in residential system sizing closely track module efficiency since 2010 (bottom figure)
- Suggests that module efficiency gains have been the driving force behind rising residential system sizing, where roof area and shading constraints are often binding

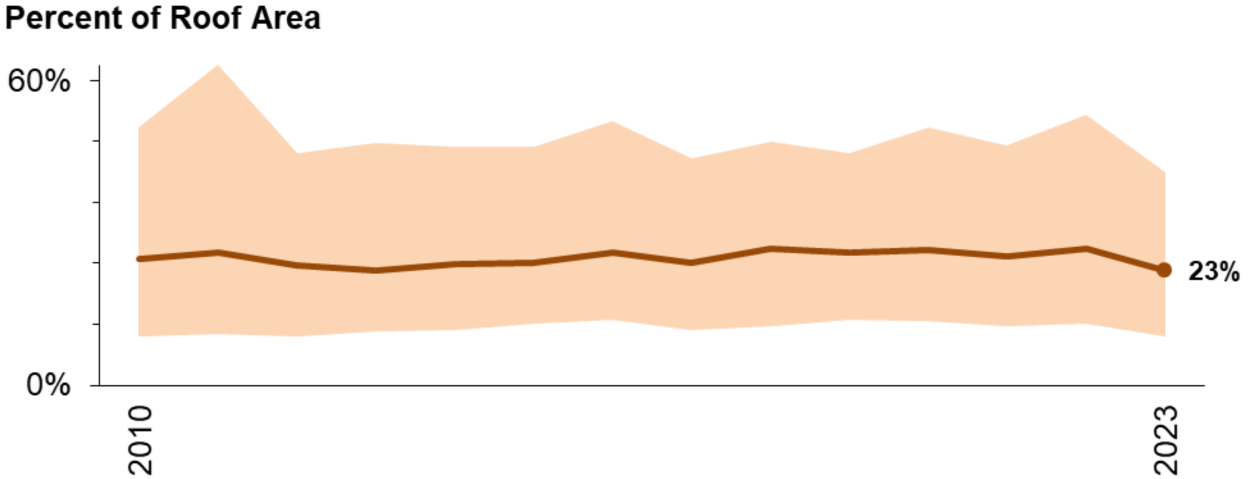
Notes: We calculate module efficiencies for each system based on the nameplate rating and surface area of the particular module model used. Both values are taken from module spec sheet data, using either the California Energy Commission's current solar equipment lists or SolarHub (a free public repository of module and inverter spec sheet data).

PV Roof-Coverage Ratios

Residential Roof-Coverage Ratio



Non-Residential Roof-Coverage Ratio

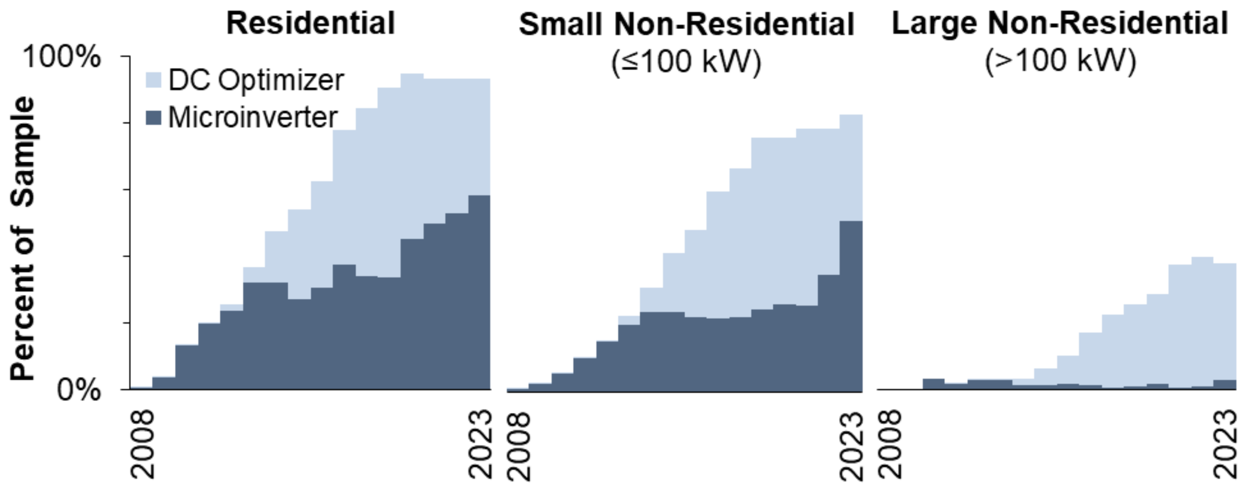


- Roof-coverage ratio is the percentage of roof-space covered with PV, calculated here based on project-specific data for module and roof area (see Notes)
- Roof-coverage ratios have been fairly stable over time, as increases in system power output have been driven mostly by module efficiency gains
- Among residential systems, roof-coverage ratios typically range from roughly 20-40% of total roof area, and are larger for multi-story homes compared to single-story
- Roof-coverage ratios vary more widely for non-residential systems, reflecting the broader range of building types and configurations

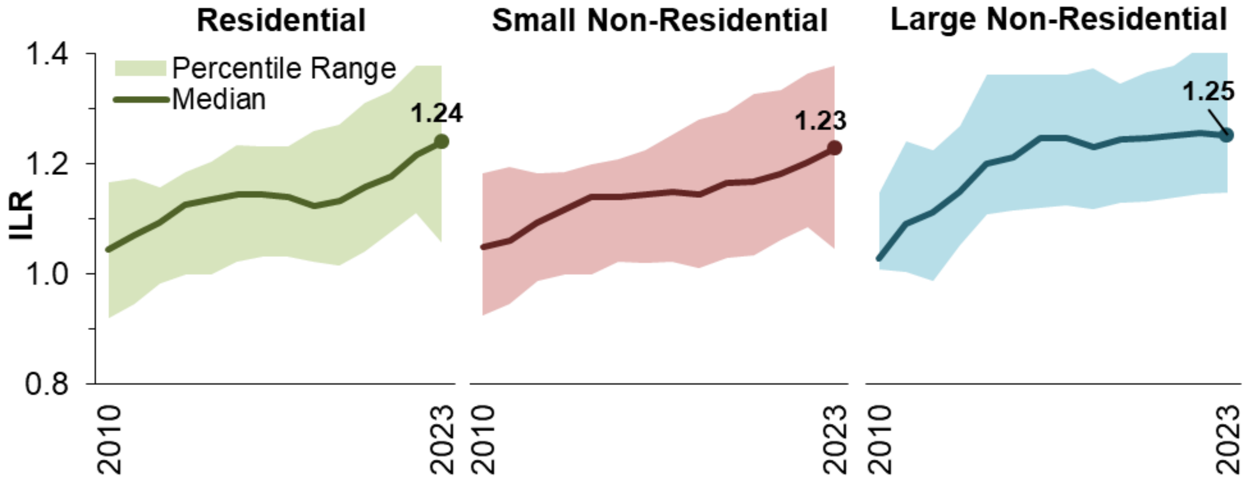
Notes: Module square footage is based on the specific module models used in each installation, with panel surface area based on spec-sheet data for those particular models (see previous slide on data sources). We approximate roof area using data from CoreLogic on the ground-floor square footage of each building, adjusted based on assumed roof tilt (20 degrees for residential and flat roof for non-residential). In some cases, ground floor square footage is estimated based on total square footage and number of stories.

Inverter Technology Trends

Microinverter and DC Optimizer Trends



Inverter Loading Ratios (DC-to-AC Ratio)

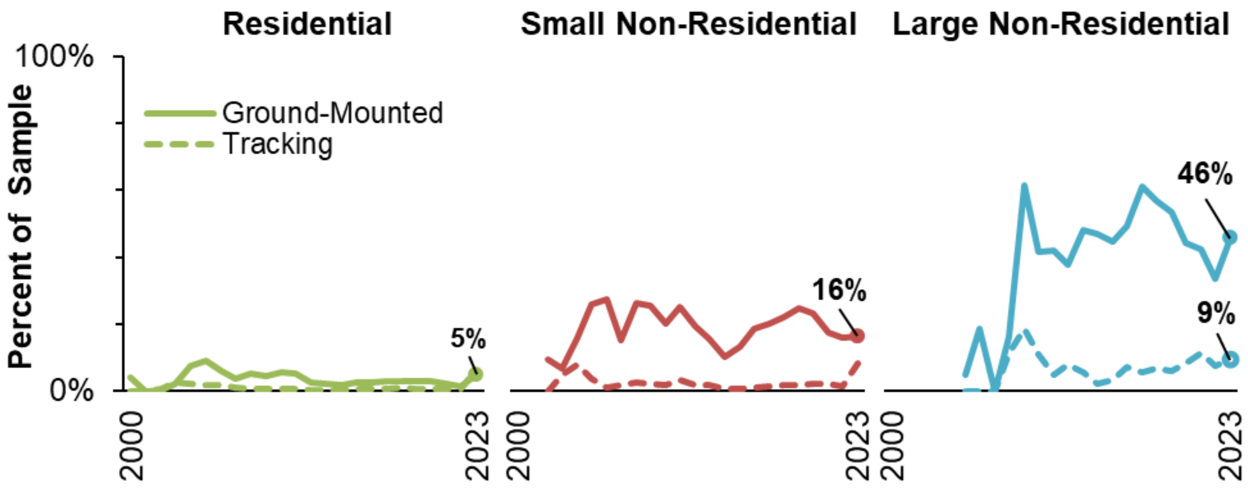


- Module-level power electronics (MLPEs), which include both microinverters and DC optimizers, have continued to gain share across the sample
- MLPEs are almost universal within the residential and small non-residential sectors (93% and 82% of 2023 installs, respectively); less common for large non-residential (38%), but optimizer-share grew substantially
- DC optimizers dominated MLPE growth from 2013-19, but microinverter share has been rising in recent years
- Inverter-loading ratios (or ILRs, the ratio of module-to-inverter nameplate ratings) have grown over time with declining module costs and microinverter share
- ILRs were historically higher for large non-residential systems, but are now roughly equivalent across sectors

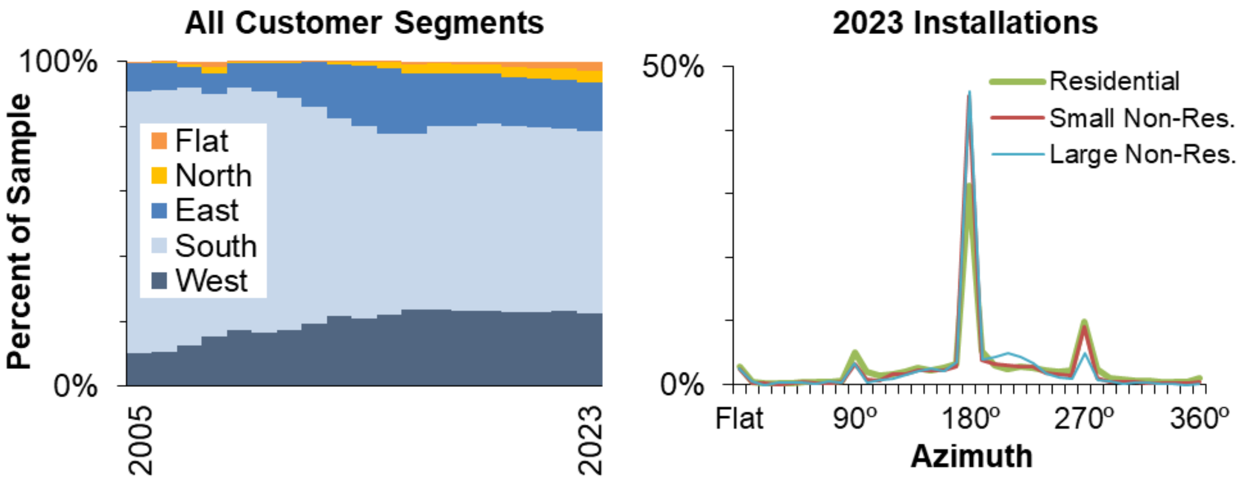
Notes: DC Optimizer share is based only on systems with SolarEdge inverters, as those are the only records in the dataset for which the presence of DC optimizers can be determined. As a result, the DC optimizer share shown in the figures may understate the actual share of power optimizers in the data sample.

Mounting Configuration and Panel Orientation

Ground-Mounting and Tracking Equipment



Panel Orientation



- Ground-mounting (as opposed to roof-mounting) is most prevalent among large non-residential systems, while use of tracking is limited
  - Almost one-half (46%) of large non-residential systems in 2023 were ground-mounted, while 9% have tracking
  - Ground-mounting much less common among residential and small non-residential systems, and negligible shares have tracking
- Panel orientations became more varied during earlier years, but haven't changed much in recent years
  - 56% of systems installed in 2023 face south, 23% to the west, and most of the remainder to the east
  - Greater share of non-residential systems faces exactly due-south, likely due to greater prevalence of ground-mounting and flat rooftops than in residential sector

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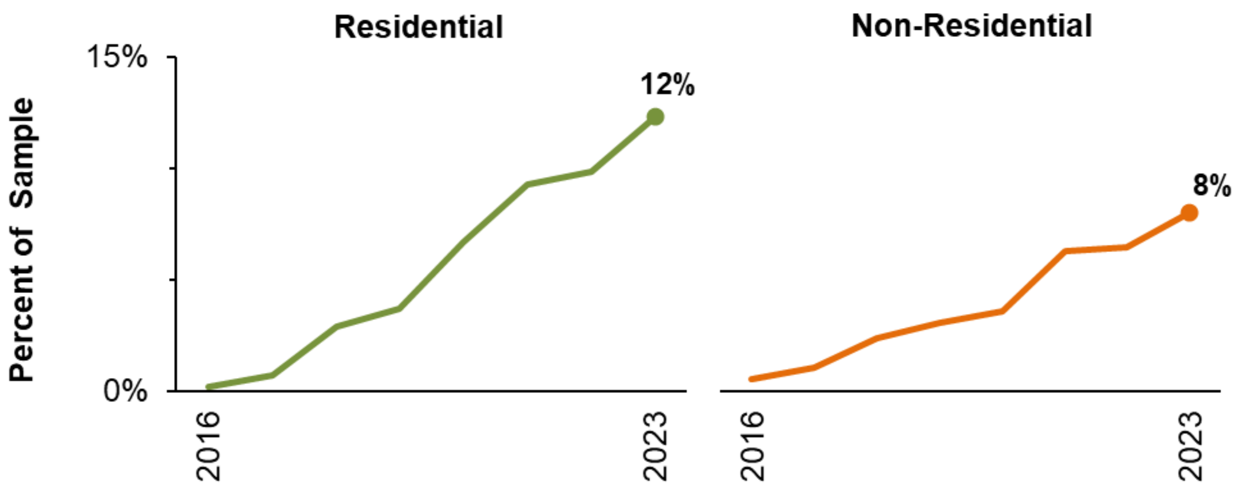
Notes: Summary statistics for any given year are shown only if at least 20 observations are available. Figures in the bottom panel exclude tracking systems, and in both figures, the orientation is based on the primary array (for systems with multiple arrays facing different directions). For the figure on the lower left, azimuths are grouped according to cardinal compass directions ±45º (e.g., systems within ±45º of due-south are considered south-facing). For the figure on the lower right, panel orientations are grouped in 10-degree bins.

Paired PV+Storage System Characteristics

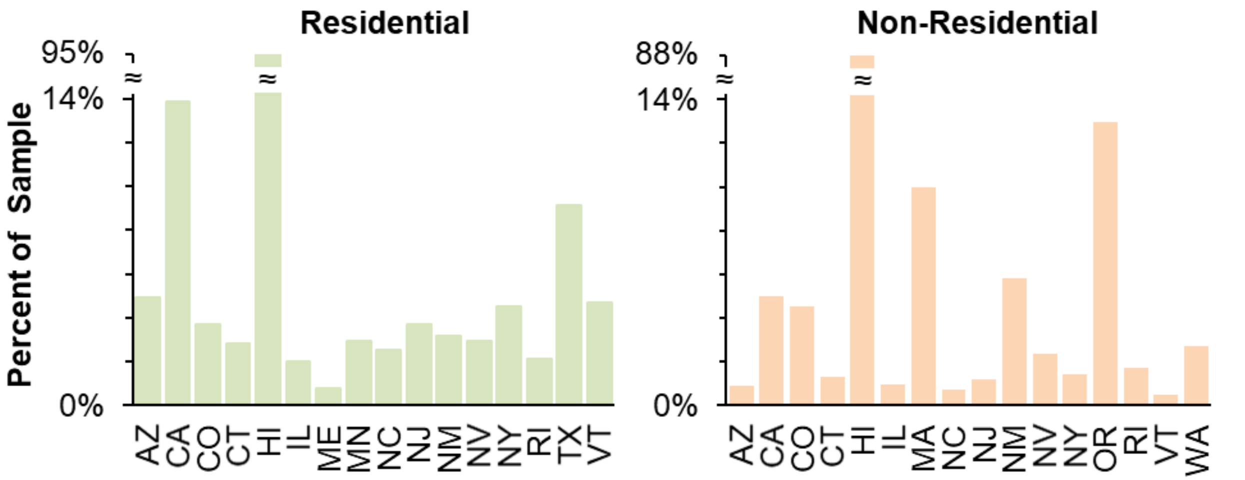
Storage Attachment Rates

Percent of PV systems installed each year with storage

Storage Attachment Rates over Time



Storage Attachment Rates by State (2023)



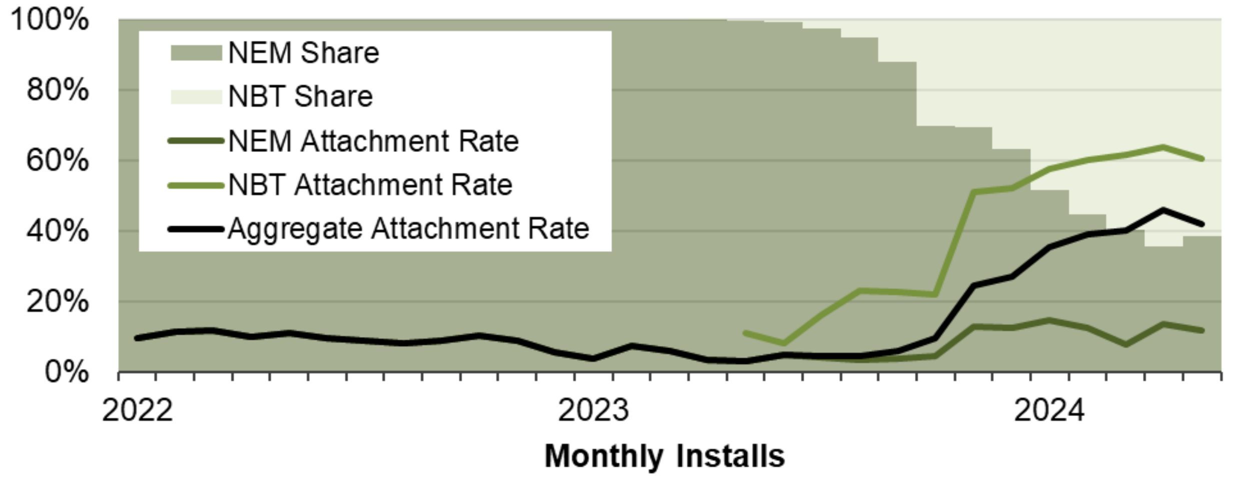
- Storage attachment rates have steadily risen over time, reaching 12% of the sample in 2023 for residential systems and 8% for non-residential
- HI has, by far, the highest attachment rates of any state—virtually all new PV has storage—driven in part by net metering reforms incentivizing self-consumption
- CA, the largest market in absolute size, had residential attachment rates of 14% last year, driven by rebates, resilience, and recent NEM reforms (see next slide)
- Most other states are seeing residential attachment rates in the range of 4-10%
- Non-residential attachment rates vary more highly across states: 88% in HI and several others above 10%, but most <2%; non-res. market more sensitive to economics and policy support, and more volatile YoY

Notes: Aggregate U.S. attachment rates are based on merging Tracking the Sun and permit data from Ohm Analytics. State-level attachment rates are based primarily on data from Tracking the Sun and are shown only if available data cover at least 50% of the state market volume. Note the breaks in the y-axes for Residential and Non-Residential systems, to accommodate data for HI.

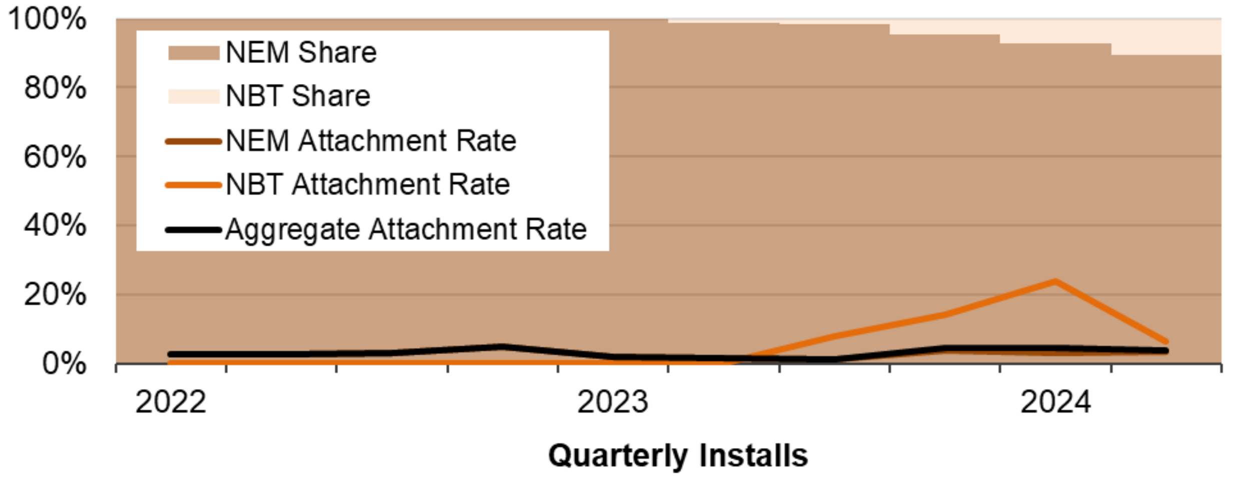
Storage Attachment Rates in California

Trends under the state's new net billing tariffs

California IOU Residential Monthly Installs



California IOU Non-Residential Monthly Installs

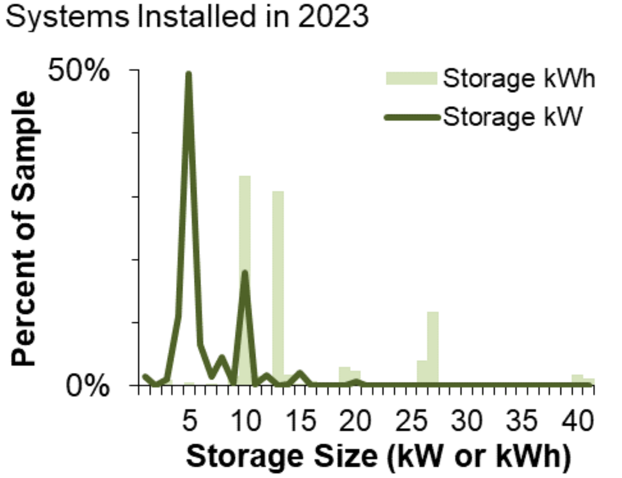


- California's investor-owned utilities (IOUs) transitioned from net energy metering (NEM) to a net billing tariff (NBT) structure, for all new PV interconnection applications submitted after 4/15/23
- The NBT structure provides lower compensation for PV generation exported to the grid, incentivizing customers to co-install battery storage
- Due to the lag between application and installation dates, the market has been slowly transitioning to NBT
- Residential attachment rates under NBT are ~60%, compared to ~10% under NEM; aggregate attachment rates rising as NBT market share grows
- Non-residential installs are still predominantly NEM, due to longer lag-time, though attachment rates under NBT are not dramatically higher than under NEM

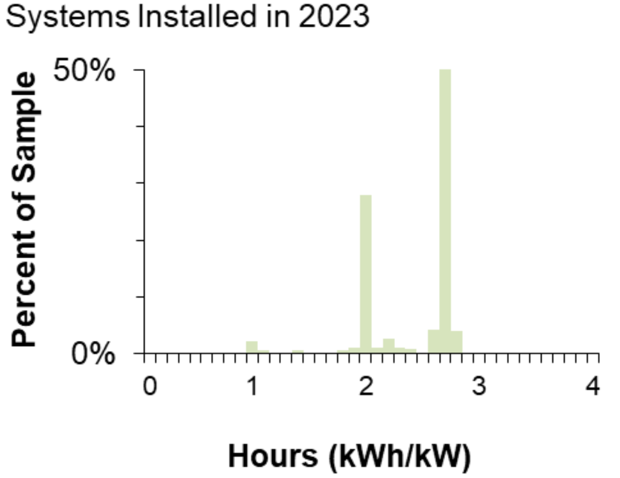
Notes: Trends are based directly on the California Public Utilities Commission's publicly available "Currently Interconnected Applications" dataset (updated through May 31, 2024). Data for non-residential systems are aggregated at the quarterly level, due to small monthly sample sizes; and data shown for Q2 2024 include only April and May installs. For a more in-depth discussion of changes in the California residential solar market under the NBT structure, please see Berkeley Lab's report, "One Year In: Tracking the Impacts of NEM 3.0 on California's Residential Solar Market."

Residential Paired System Sizing

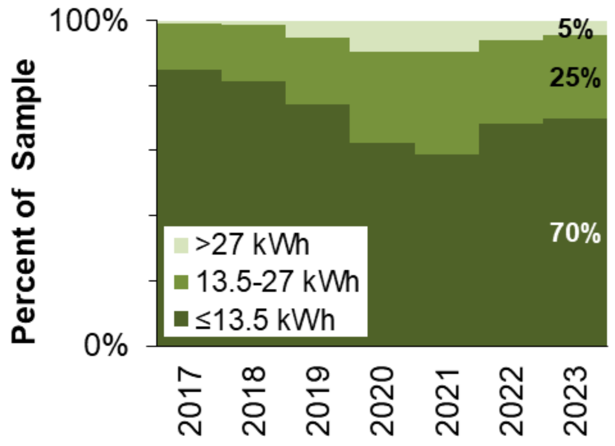
Storage Size Distribution



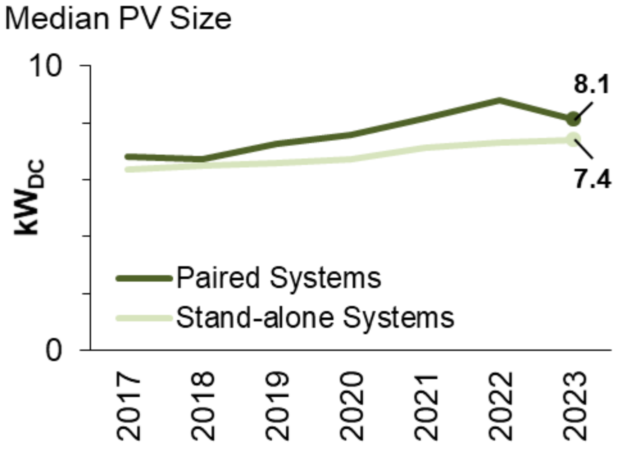
Storage Duration



Storage Size Trend



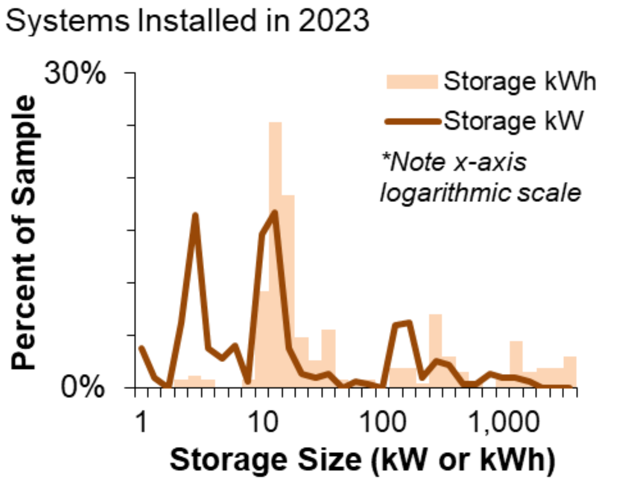
PV Size Trend



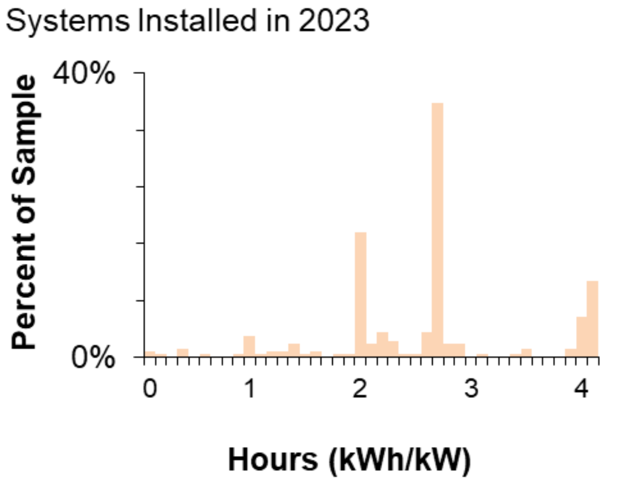
- The majority of paired residential systems consist of a single battery with 10 or 13.5 kWh of storage and a rated (max continuous) power output of 5 kW
- Given those product specs, most residential batteries have a duration of 2 to 2.7 hours
- The market had been trending toward systems with larger amounts of storage capacity, potentially driven by backup power demand, but reversed course the past several years as the market became more geographically diversified
- PV systems paired with storage tend to be slightly larger than stand-alone PV systems, despite the fact that paired systems are more heavily concentrated in CA, where PV sizes tend to be small

Non-Residential Paired System Sizing

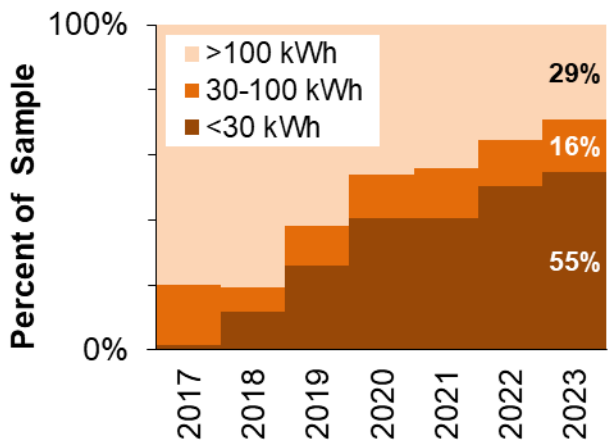
Storage Size Distribution



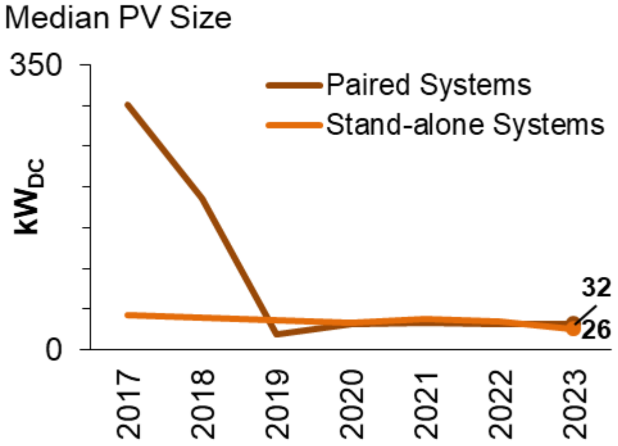
Storage Duration



Storage Size Trend



PV Size Trend

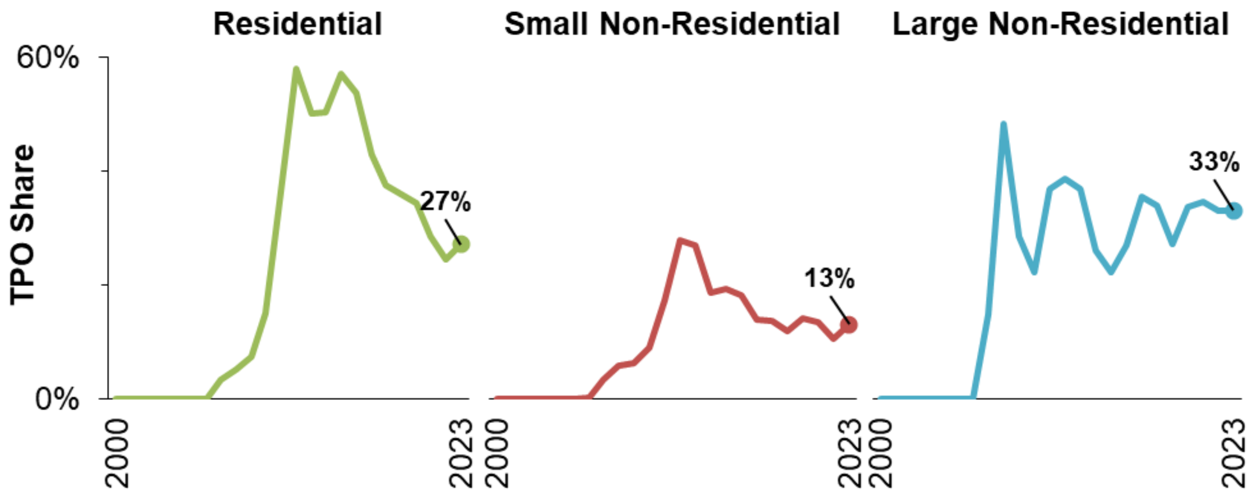


- Storage sizing in paired non-residential applications is much more varied than for residential systems, though the majority have relatively small amount of storage (many with just a single 5 kW / 10-13.5 kWh battery)
- Storage durations are similar to residential, though a more significant share of systems (16%) have longer-duration (4+ hour) batteries
- Paired applications in the non-residential market have been moving into progressively smaller applications in recent years; no longer primarily the domain of large users with high demand charges
- This can be seen in both the storage sizing and PV sizing trends for paired systems (the latter now roughly in line with the broader non-residential PV market)

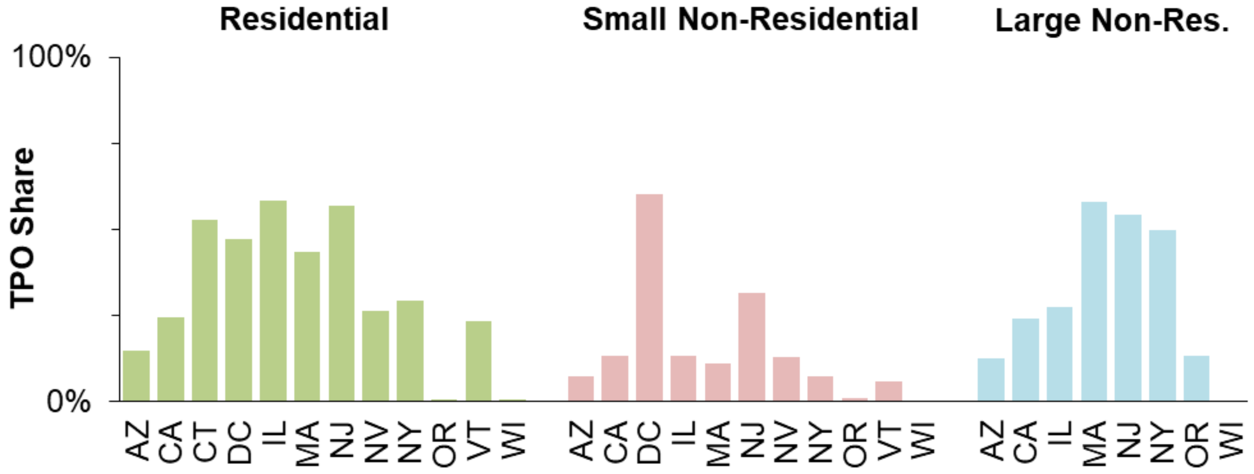
Third-Party Ownership and Customer Segmentation

Third-Party Ownership Trends

Third-Party Ownership Trends



Third-Party Ownership by State (2023)

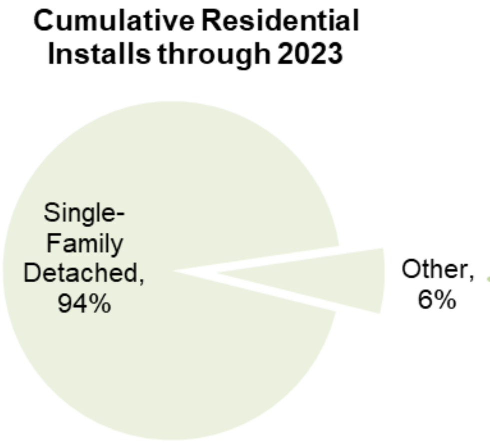


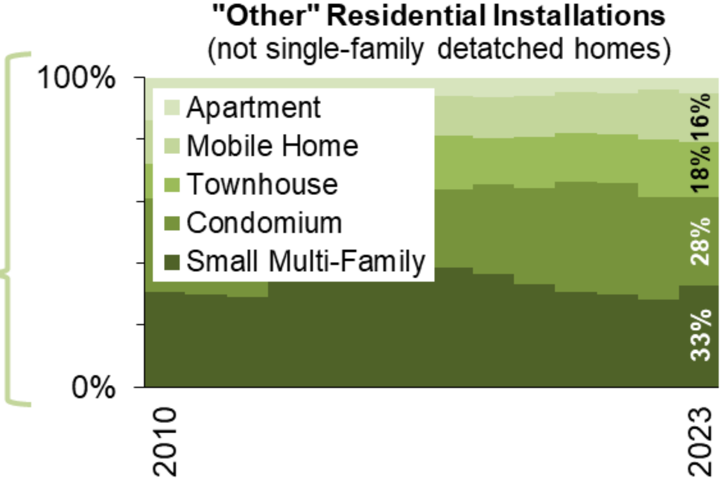
- Third-party ownership (TPO) in the residential sample remains well below its historical high of ~60% in 2012
  - Slight uptick in 2023 to 27%, as interest rates on solar loans rose
  - May foreshadow further rise as TPO systems can access higher tax credits under the Inflation Reduction Act
- For the non-residential sample, TPO shares have remained comparatively steady and have historically been lower for small vs. large non-residential systems
- TPO shares at the state level vary substantially
  - Generally higher in states with high solar renewable energy certificate prices (DC, MA, NJ) or other lucrative incentive programs (CT, IL, NY)
  - Some states limit TPO or restrict eligibility for incentive programs to only host-owned systems

Notes: In the bottom figure, data are shown for individual states only if TPO status is available for at least 20 systems and for at least 50% of records for the given state, year, and customer segment. Furthermore, we exclude a number of states from the figure where the underlying data source may not be representative of the state as a whole, in terms of TPO shares.

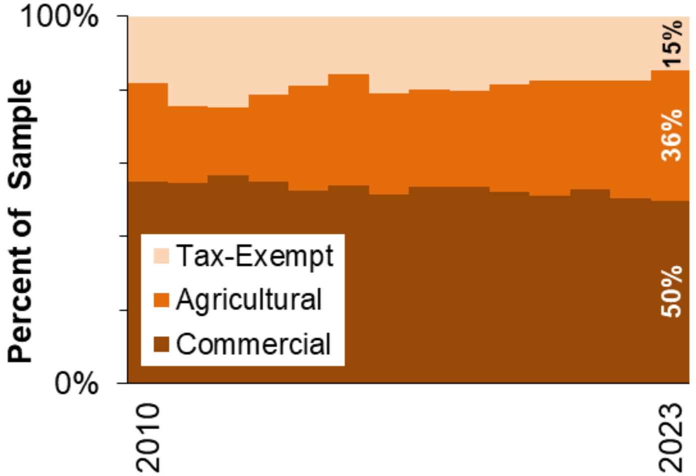
Customer Segmentation

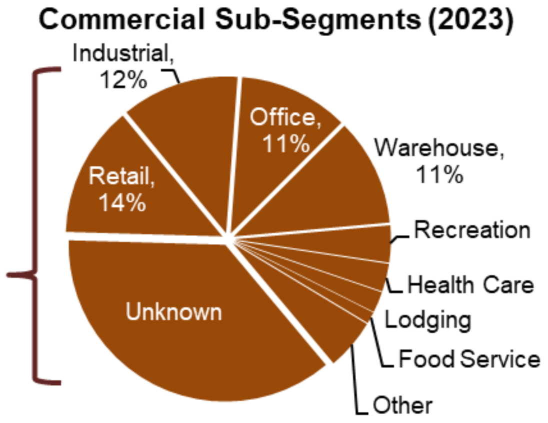
Residential Systems





Non-Residential Systems





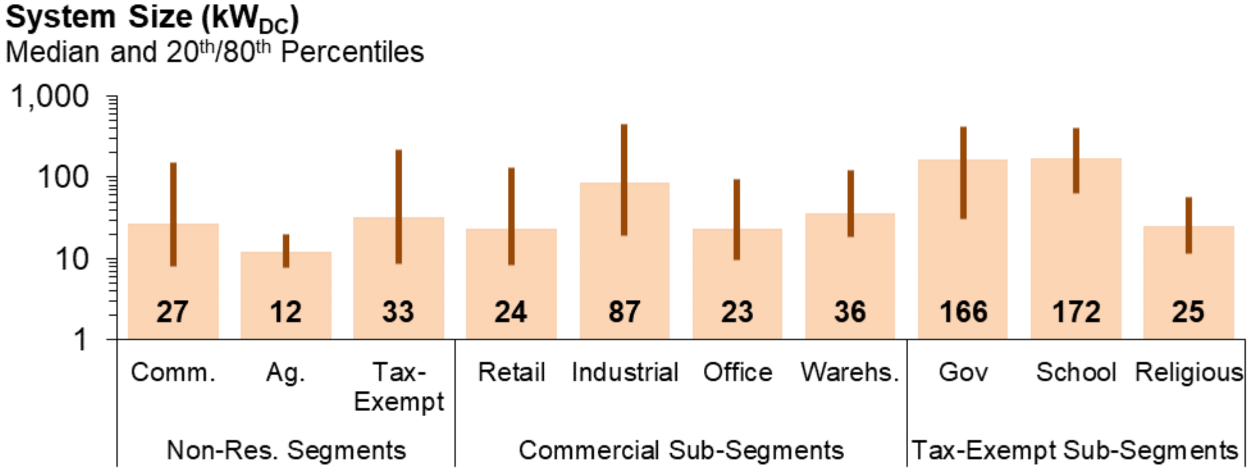
- Residential systems are overwhelmingly installed on detached single-family homes
- Other types of residential installations are mostly on small multi-family buildings (e.g., duplexes), condos, townhomes, and mobile homes; a small percentage are on apartments or other large multi-family buildings
- Among non-residential systems, half are installed on commercial buildings, roughly one-third on agricultural land, and the remainder by tax-exempt customers (schools, government, houses of worship, etc.)
- Commercial systems span a diverse range of sectors, the largest being retail, industrial, office, and warehouse buildings (though about a third of all commercial systems have no identified building type)

Notes: Customer segmentation is based on detailed land-use codes from CoreLogic, which are derived from county records and can vary from county to county in terms of how particular land-use types are defined. Berkeley Lab aggregates those land use codes into the particular categories presented here.

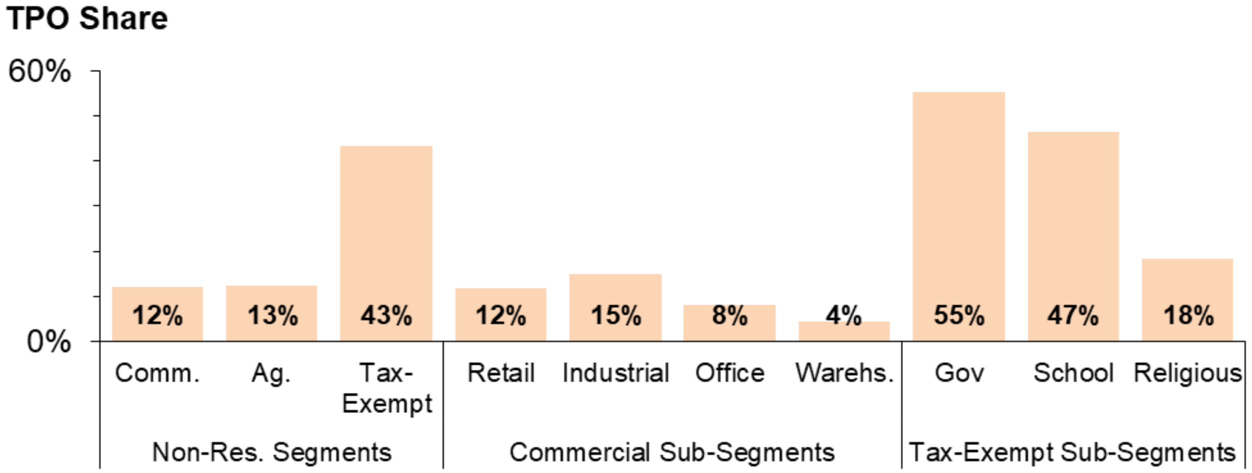
Non-Residential Segmentation Details

System sizing and TPO rates

System Sizing (2023 Non-Residential Systems)



Third-Party Ownership (2023 Non-Residential Systems)



- The largest system sizes are at school and government facilities, as well as industrial properties; system sizes in all other segments are significantly smaller (medians <40 kW)
- Systems installed on agricultural properties tend to be quite small (mostly in the 10-20 kW range); many of these are likely on small family farms, partly serving residential loads
- TPO rates are much higher for systems installed by tax-exempt site hosts, in order to monetize tax credits (direct-pay may reduce that driver going forward)
- Religious facilities are notably less likely to utilize TPO, reflecting preferences for direct ownership and/or challenges in accessing TPO

Notes: See previous slide for data sources used to define customer segments. The figures include only the most common commercial and tax-exempt sub-segments; other and unknown sub-segments are omitted for brevity.

Median Installed Price Trends

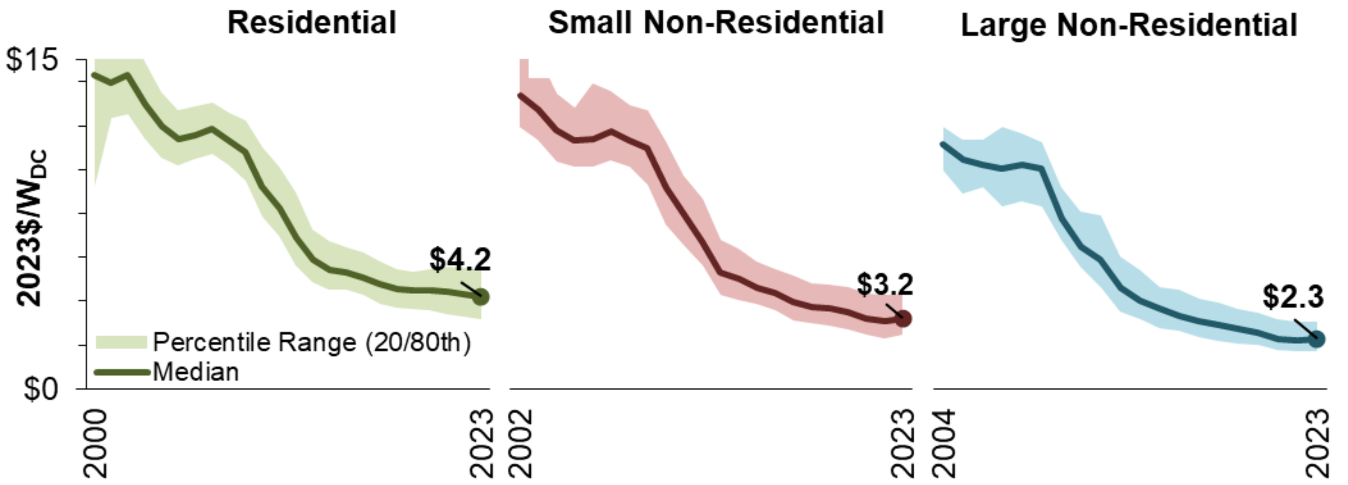
A Few Notes on Installed-Price Data

- Focus is on stand-alone PV systems only (unless otherwise noted)
- Excludes third-party owned (TPO) and self-installed systems
- Price represents what the host customer paid for the system, before any incentives
- Data are self-reported by PV installers or customers
- May include dealer fees for loan-financed systems and other ancillary items related to the PV installation (e.g., electrical and roofing)
- Prices are adjusted for inflation, unless otherwise noted

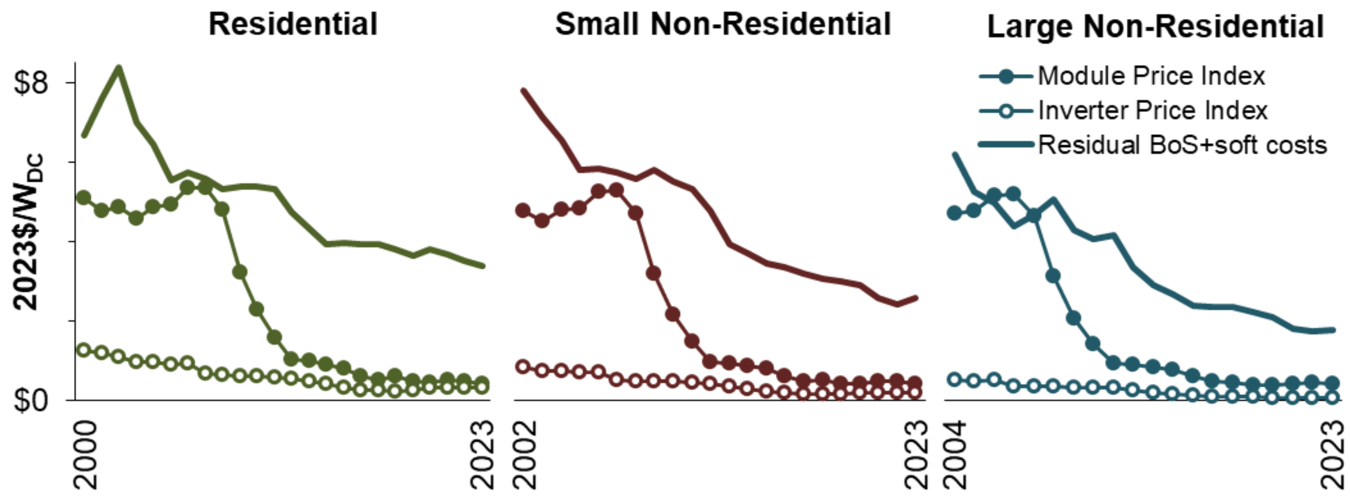
Long-Term Trends in Median Prices and Component Costs

Stand-alone PV systems

National Installed Prices over Time (Inflation-Adjusted)



Underlying Trends in Component Costs



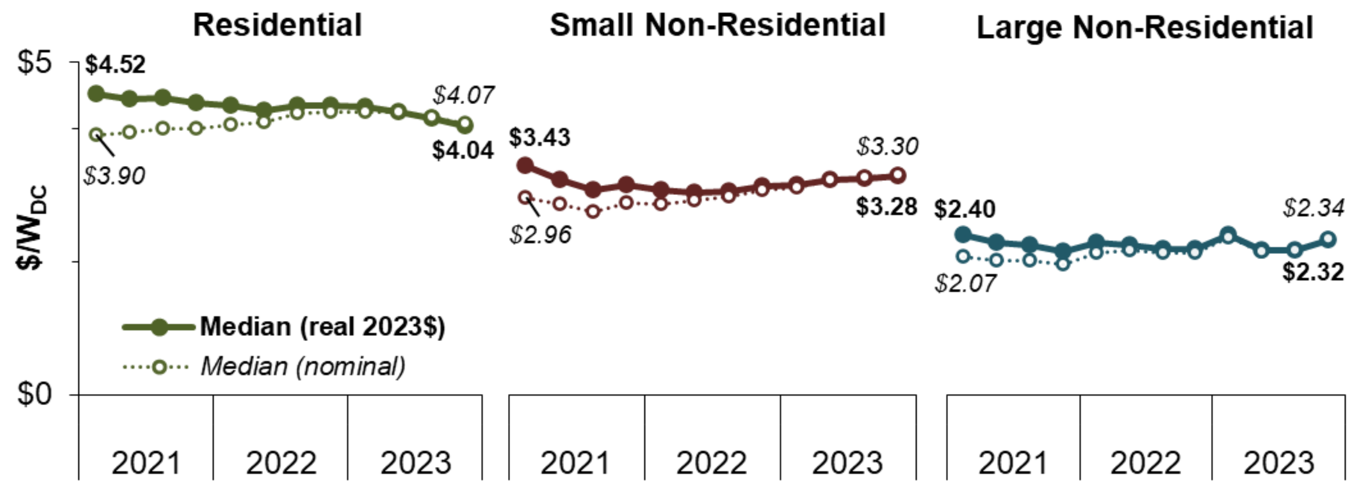
- Installed prices over the past decade have been falling at a relatively steady pace of about $0.1-0.2/W per year
- The steep price declines in earlier years were driven by falling module costs; the current trajectory is instead driven primarily by changes in soft costs
- From 2022 to 2023, median installed prices for residential systems fell by roughly $0.1/W in real (inflation-adjusted) terms, maintaining the same trajectory 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 can be 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

Notes: Summary statistics for any given year are shown only if at least 20 observations are available. The Module and Inverter Price Indices are based on data from SPV Market Research and Wood Mackenzie, with adjustments by Berkeley Lab in order to extend those indices back in time and to differentiate among customer segments. The Residual term is calculated as the median installed price for each customer segment minus the corresponding Module and Inverter Price Indices in the preceding year (to reflect some supply-chain lag).

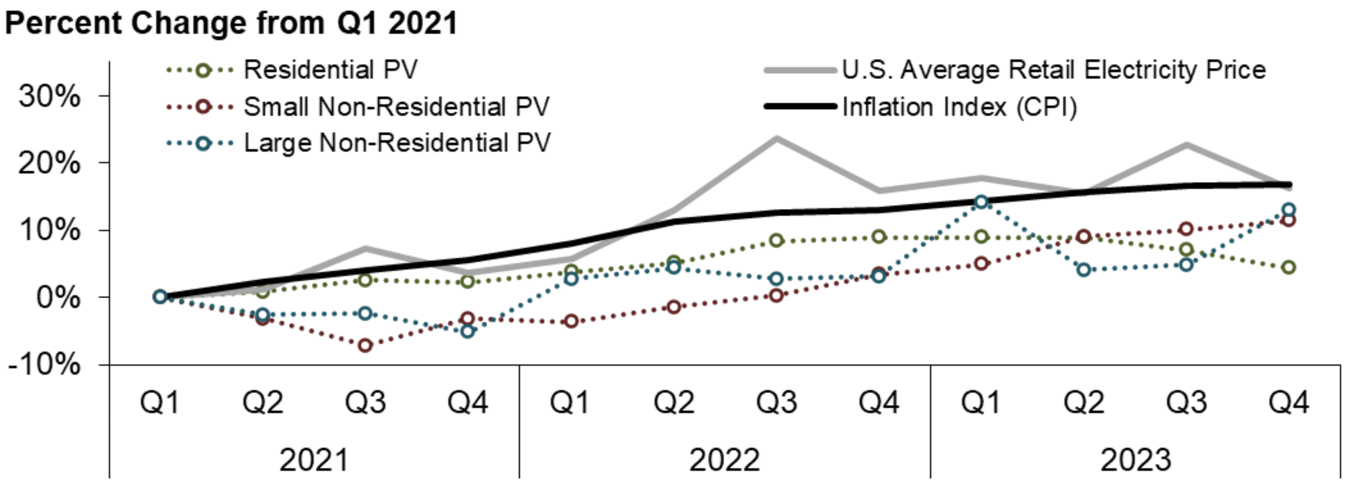
Recent Trends in Median Installed Prices (2021-2023)

Stand-alone PV systems

Quarterly Median Installed Prices: Real vs. Nominal



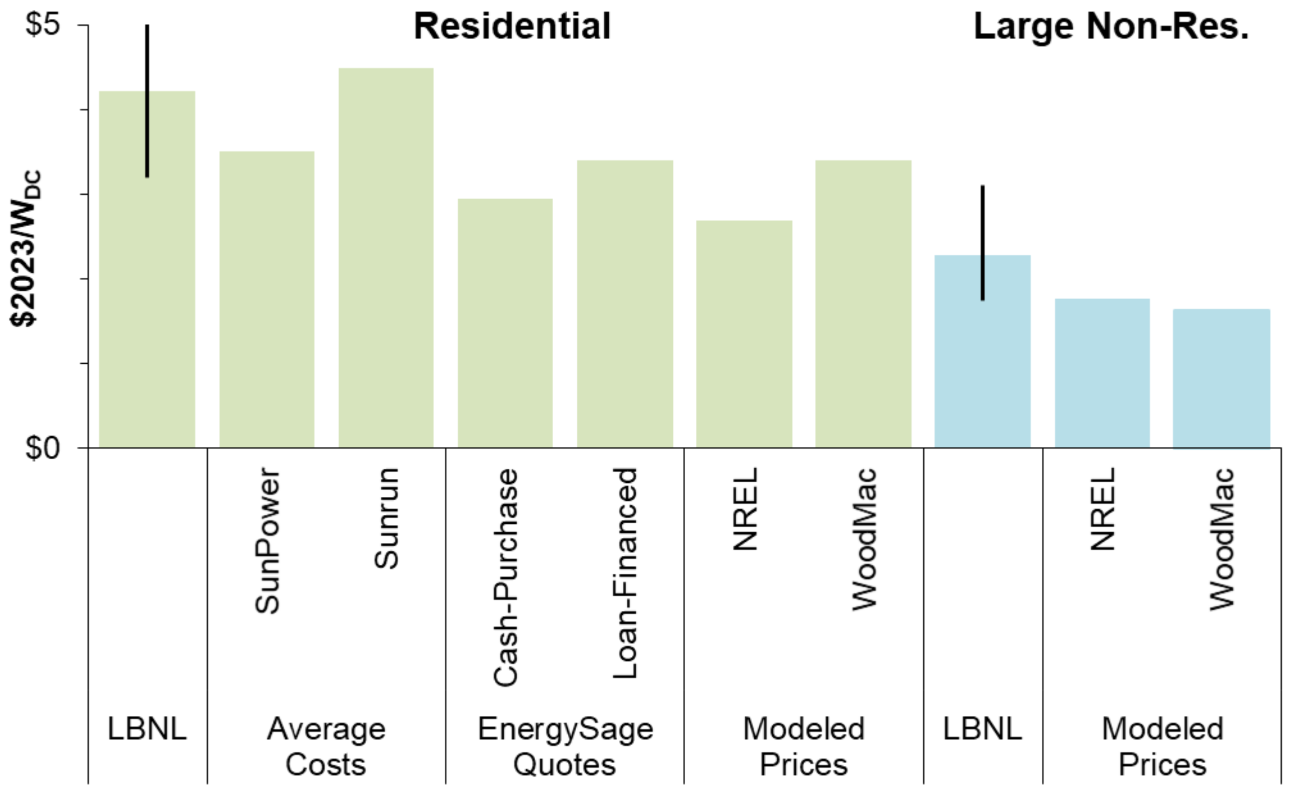
Nominal Price Trend Relative to Inflation and Utility Rates



- Focusing here on quarterly prices over (more-or-less) the period since U.S. inflation rates began to rise…
- *Nominal* installed prices rose by $0.2-0.3/W across the three customer segments
- But *real*, inflation-adjusted prices fell by roughly $0.5/W for residential systems and by $0.1/W for non-residential
- The fact that real prices fell suggests that PV pricing has thus far been less impacted by inflation compared to other consumer goods (as measured by the CPI), though the effects on installed prices for large non-residential systems may have not yet entirely materialized (given long development timelines)
- Perhaps just as important, PV prices have risen more slowly than average U.S. retail electricity prices (though changes in rate structure are also impacting the customer-economics of PV in some jurisdictions)

*Throughout our analysis, we translate installed PV prices from nominal to real dollars using the Bureau of Labor Statistics' CPI for All Urban Consumers, U.S. city average, All items. U.S. average retail electricity prices are calculated from sales and revenue data published by the U.S. Energy Information Administration (Form 861M).

Comparison to Other PV Cost and Pricing Benchmarks



*Notes: **LBNL** data are the median and 20th and 80th percentile values among projects installed in 2023. Average costs from **SunPower and Sunrun** data are based on the companies' quarterly shareholder reports in 2023 (courtesy of J. Zuboy, NREL) and include reported installation, sales, and general & administrative costs, averaged across quarters. **EnergySage** data are the median price quotes issued in 2023, for either cash-purchased or loan-financed stand-alone PV systems, as calculated by Berkeley Lab from data provided by EnergySage. **NREL** data represent modeled market price in Q1 2023 for a 8 kW residential system and a 3000 kW ground-mounted community solar system (Ramasamy et al. 2022). **WoodMac** data are from the Solar Market Insight 2023 Year-in-Review, and are based on modeled turnkey prices, averaged across quarters.*

- A variety of other PV cost and pricing benchmarks exist, based on differing methods and data sources, and serving different purposes
- On the residential side, national median installed prices from Tracking the Sun (TTS) are similar to average costs reported by Sunrun, but other benchmarks align more closely with 20th percentile pricing from TTS
- On the non-residential side, fewer benchmarks are available and are limited to large systems, which also align more closely with 20th percentile levels from TTS
- Divergence with other benchmarks can reflect factors such as price vs. cost, quotes vs. actuals, mark-ups, system design, and scope of costs included
- Of particular note: TTS prices likely include dealer fees for loan-financed systems, adding 5-50% to the overall reported price for those systems

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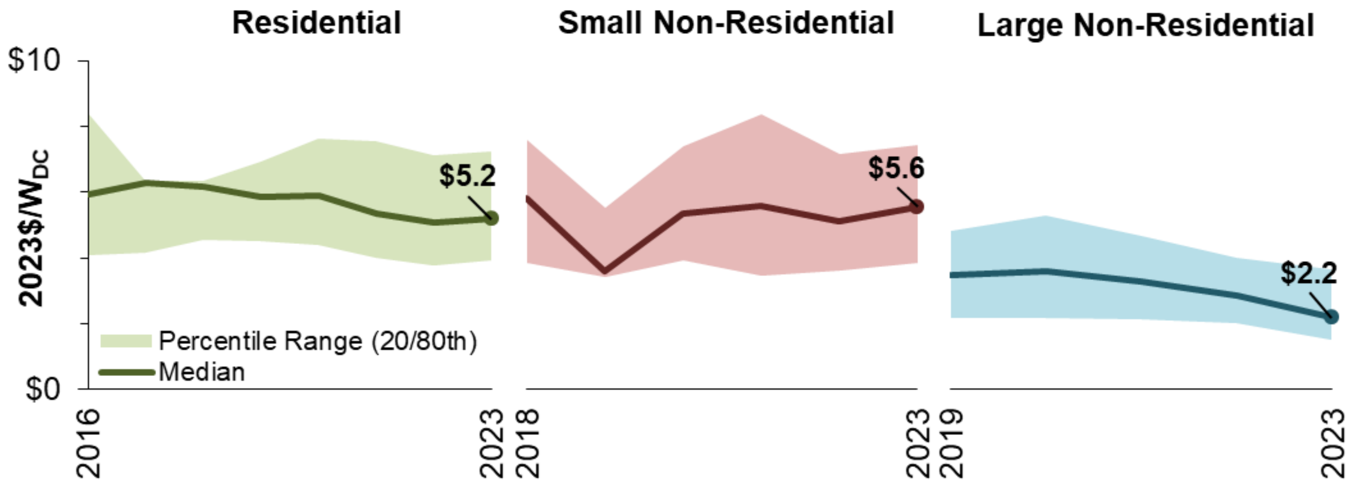
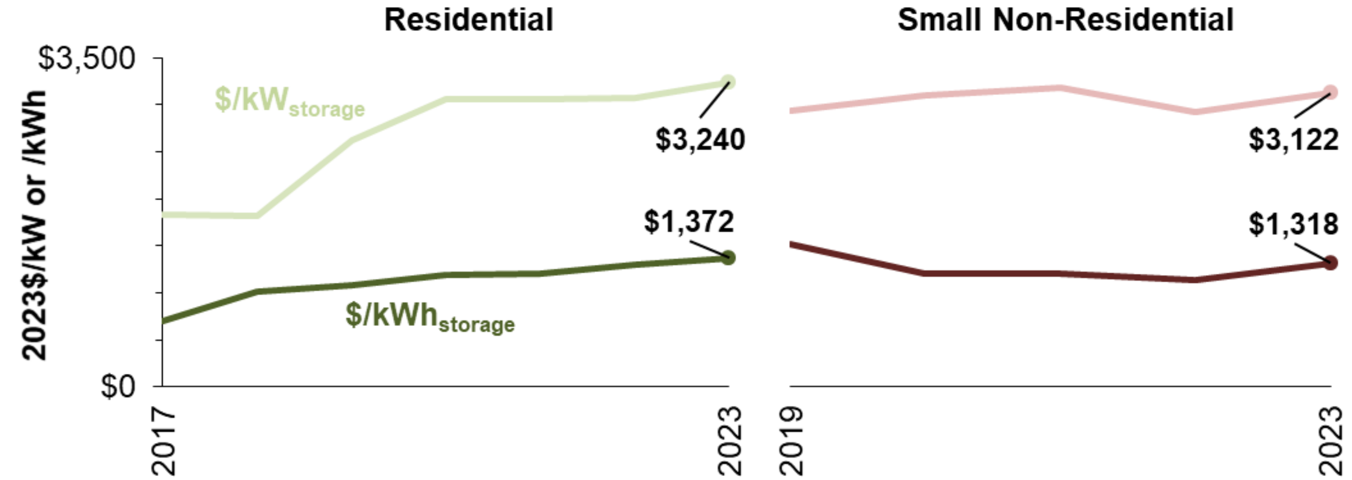
Installed Prices for Paired PV+Storage Systems

Total Installed Prices for Paired Systems ($\$/W_{PV}$)



Median Reported Battery Cost Only (inclusive of installation)



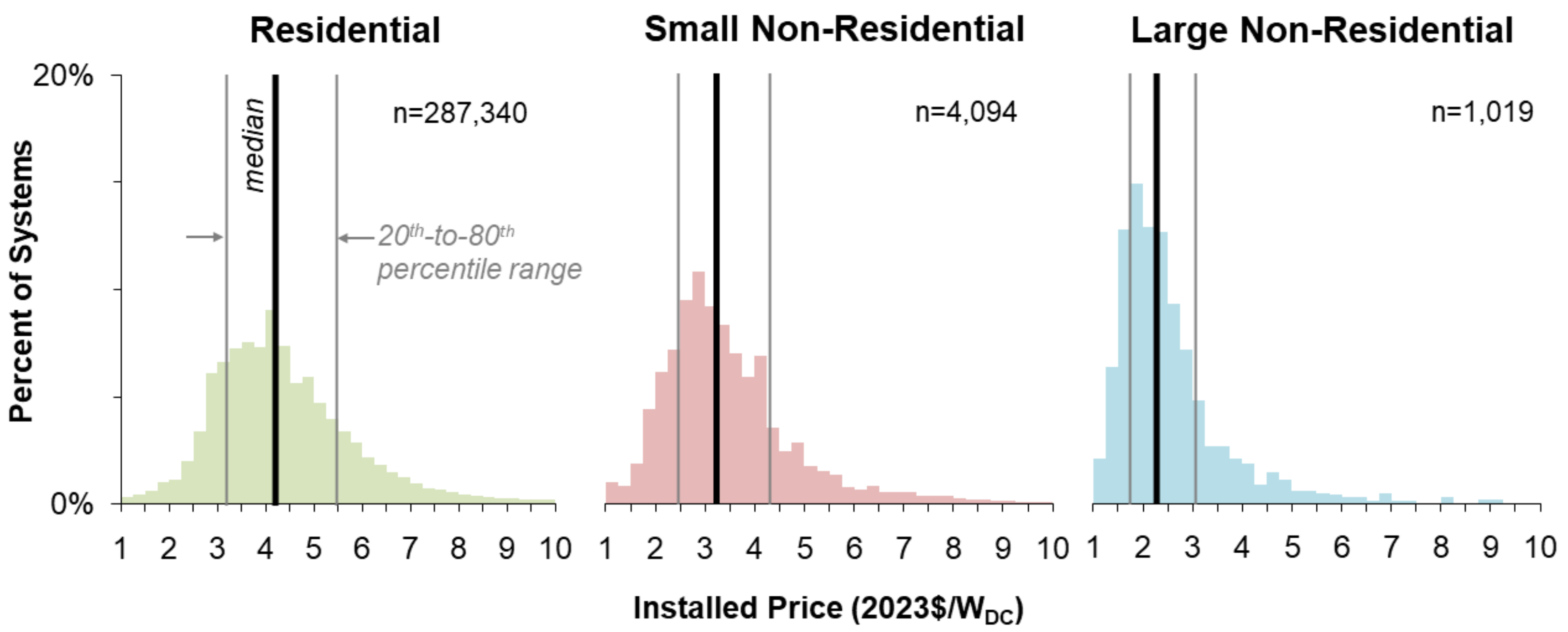
- Top figure presents *total* installed prices for paired systems in terms of *$ per watt of PV capacity*
- Median prices for paired residential and large non-residential systems have been declining over time; trends are less clear for small non-residential systems
- Trends in total installed prices reflect changes both in the underlying PV and battery storage costs, as well as any other confounding trends (e.g., in where systems are installed)
- Bottom figure presents reported costs for *just the battery component* (based on a more limited dataset)
- As shown, battery costs (including installation-related) have generally been rising or have remained flat
- Note that the later multi-variate regression analysis implies a price premium of roughly $750-1000/kWh of storage for paired residential systems in 2023

Notes: Summary statistics for any given year are shown only if at least 20 observations are available, thus the differing time frames shown in the top figure for each of the three customer segments. Statistics for paired systems exclude retrofits to existing PV systems. Reported battery costs come primarily from California's Self Generation Incentive Program.

Variability in Installed Prices

Installed-Price Variation Across Systems

Installed-Price Distribution for Stand-Alone PV Systems Installed in 2023



20th to 80th Percentile Bands for Systems Installed in 2023

- \$3.2/W - \$5.5/W (residential)
- \$2.5/W - \$4.3/W (small non-residential)
- \$1.7/W - \$3.1/W (large non-residential)

- Wide pricing variability persists within each customer segment
- Reflects underlying differences in:
  - Project characteristics
  - Installer attributes
  - Local market, policy, and regulatory environment
- We explore a subset of pricing drivers in the following slides, through a combination of ***descriptive analysis*** and a multi-variate ***regression model***
  - A variety of other studies have also investigated pricing drivers, often leveraging TTS data

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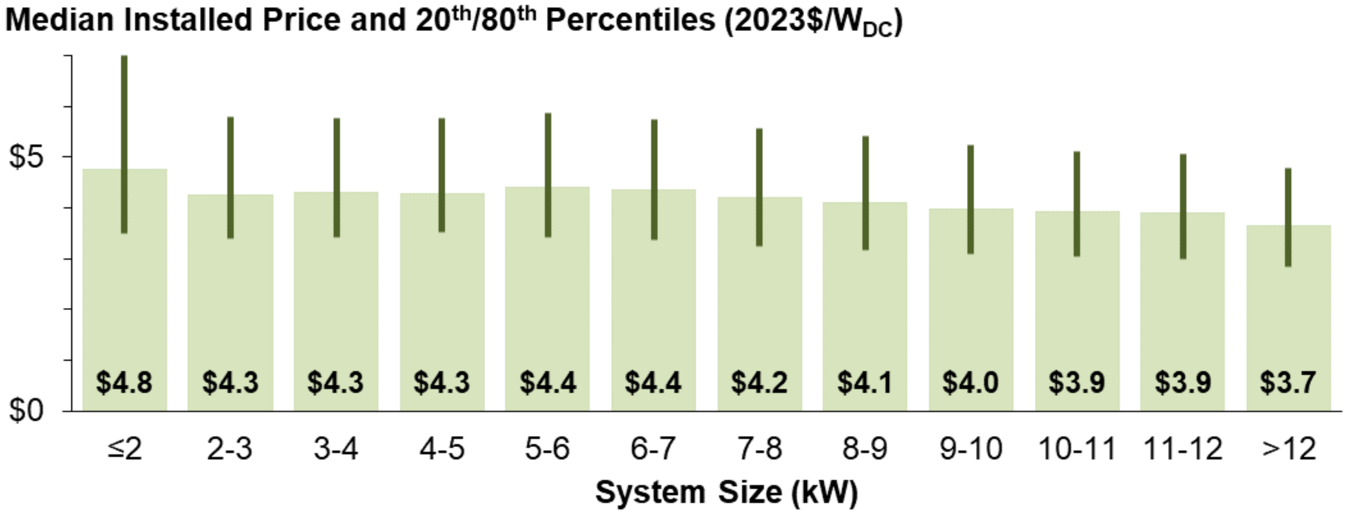
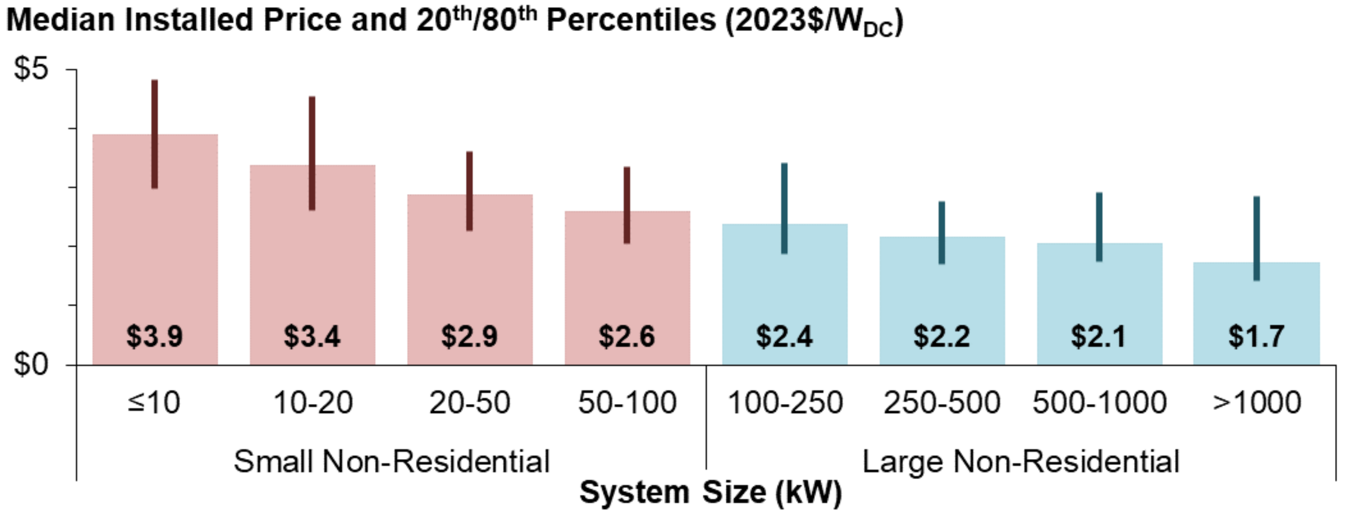
Economies of Scale with PV System Size

Residential Systems Installed in 2023



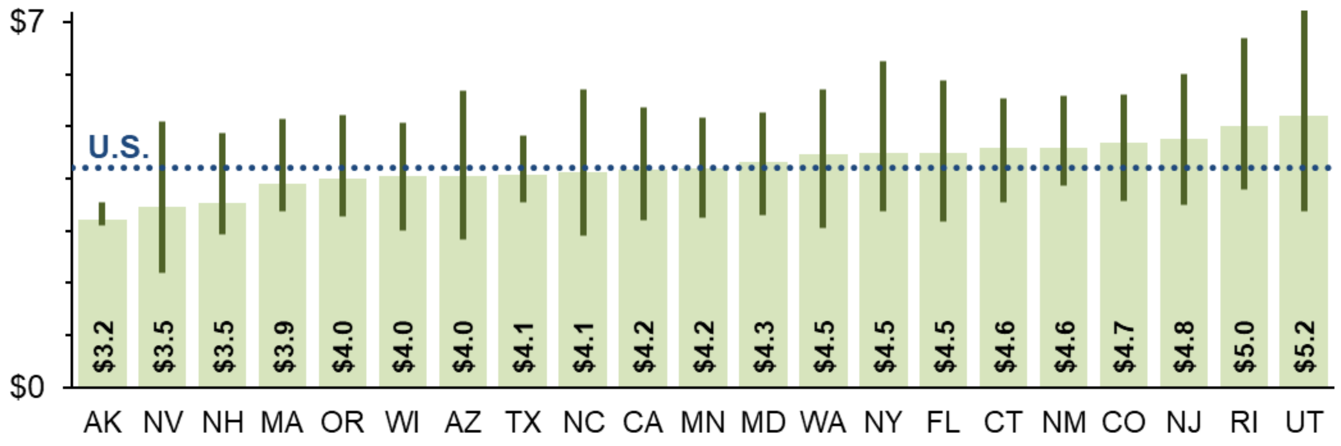
Non-Residential Systems Installed in 2023



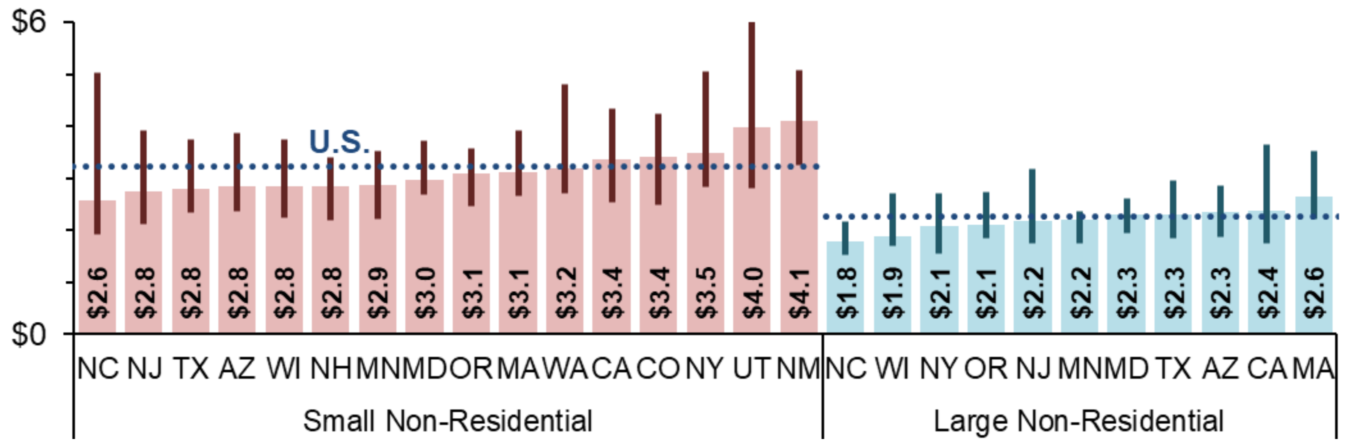
- Economies of scale arise because of the many fixed costs (e.g., permitting, customer acquisition, financing, etc.)
- Among residential systems installed in 2023, median prices were roughly $1.0/W lower for the largest residential systems compared to the smallest; later regression model provides a more precise estimate
- Among non-residential systems, which span an even wider size range, median prices were $2.2/W lower for systems >1,000 kW, compared to the smallest non-residential systems ≤10 kW

State-Level Differences in Installed Prices

Residential Systems Installed in 2023



Non-Residential Systems Installed in 2023

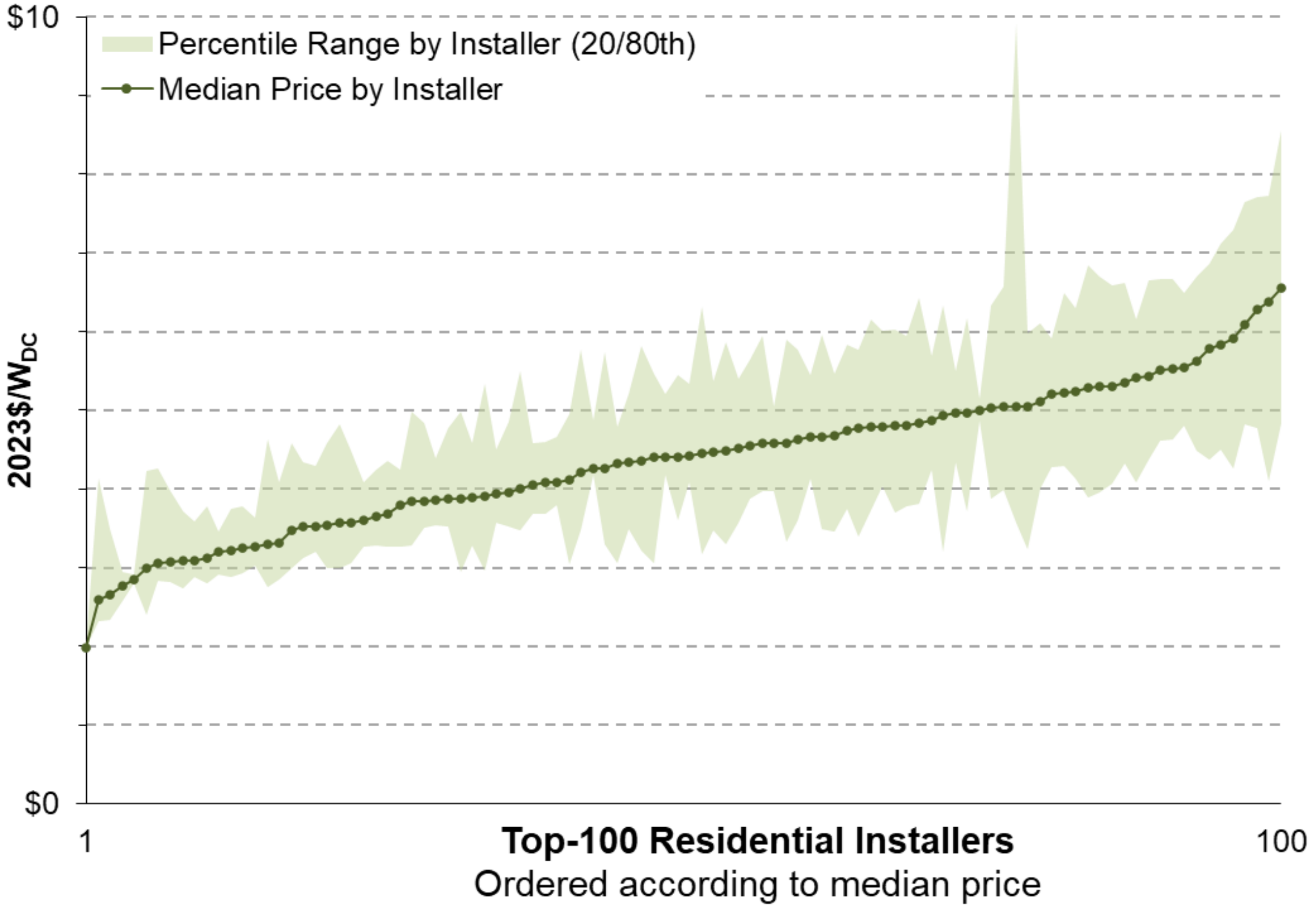


- Median prices vary across states within each customer segment, particularly for residential and small non-residential
- Residential pricing in CA, which dominates the sample, is near the middle of the pack for residential
- Cross-state pricing differences can reflect idiosyncratic features of particular states (e.g., a single large installer with anomalous prices) as well as more-fundamental differences in market and policy conditions
- The regression analysis controls for some of those fundamental drivers (e.g., market size, population density, income levels), though still shows substantial cross-state differences

Notes: Summary statistics for any given state are shown only if at least 20 observations are available.

Installer-Level Pricing Differences

Top-100 Host-Owned Residential Installers in 2023

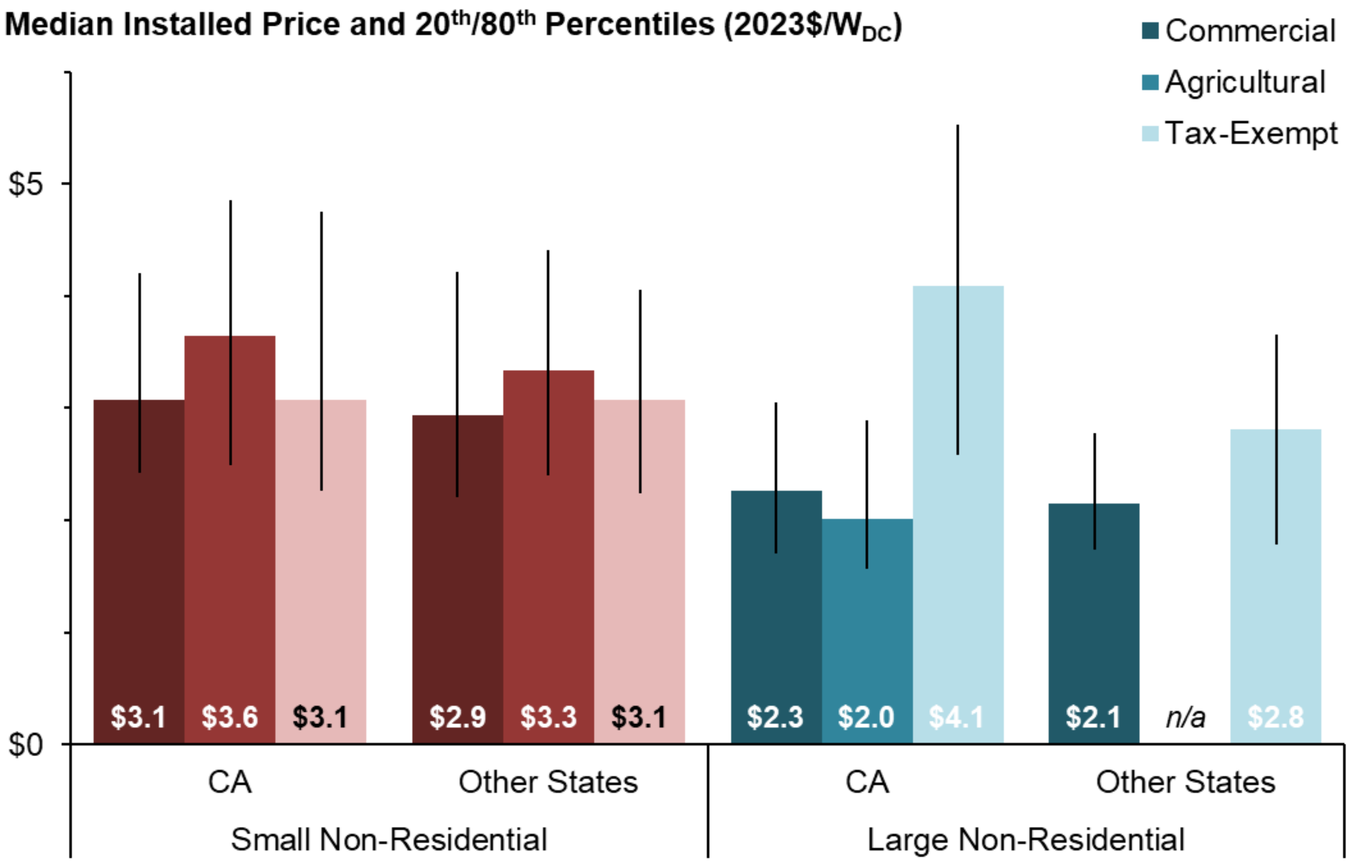


Notes: Each dot represents the median installed price of an individual installer, ranked from lowest to highest, while the shaded band shows the 20th to 80th percentile range for that installer.

- Ignoring outliers, median prices across the top-100 residential installers in 2023 ranged from $2.6 to $5.9/W
- Roughly one-third had median prices below $4/W, while one-third had prices between $4-5/W, and the remainder had median prices above $5/W
- Differences in installer-level pricing reflect firm-level characteristics (e.g., vendor relationships, business models), features of the local markets in which each installer operates, as well as differences in how each installers report prices
- Firm-level experience is one potential contributor, though regression analysis suggests a rather small effect
- Wide variability in pricing across projects by individual installers (shaded area) reflects unique features of individual projects and customers

Installed-Price Differences by Non-Residential Segment

Non-Residential Systems Installed in 2023



Notes: Summary statistics provided only if underlying data sample consists of at least 20 observations.

- Among small non-residential systems, price differences across segments are relatively small, though agricultural systems tend to be slightly more expensive
  - Possibly due to additional costs of ground-mounting and the limited potential for economies of scale
- Among large non-residential systems, prices are higher for tax-exempt site hosts (schools, government, non-profits), especially in California, potentially reflecting:
  - requirements for domestically manufactured components or prevailing wage/union labor
  - prevalence of shade or parking structures
  - lower borrowing costs

Multi-Variate Regression Analysis of Residential Installed Prices

Econometric Model Overview and Results

- Multi-variate linear-regression model to explain variation in prices for ***host-owned, residential systems installed in 2023***

$$p = \alpha + system\beta_1 + market\beta_2 + installer\beta_3 + home\beta_4 + S + Q + \varepsilon_i$$

- Dependent variable (*p*) is installed price (in $/W); independent variables include system, market, installer, and home construction factors, as well as state (*S*) and quarterly (*Q*) fixed-effects; many of the system-related variables are binary
- Complements the descriptive analysis by showing the effects of individual pricing drivers while controlling for inter-dependencies among those factors
- Coefficients in the table represent the average change in PV installed price ($/W) given a unit change in each of the variables listed (or, for binary variables, if that variable is true)
- Not all coefficients are statistically significant; R^2 metric indicates that the model explains 12% of the overall variability in prices

Variable		Coefficient
System	System size (kW)	-0.21*
	System size squared	0.005
	Premium module (binary)	0.01
	Microinverter (binary)	0.12*
	DC optimizer (binary)	0.40*
	Ground-mounting (binary)	0.40*
	Battery storage (binary)	1.45*
Market	Market size (x1,000)	-0.02*
	Population density (x1,000)	0.04
	Median zip-code income (x10,000)	-0.004*
Installer experience (x1,000)		-0.01*
Home	New construction (binary)	-0.71*
	Year of construction	-0.005*
	N	266,903
	R^2	0.12

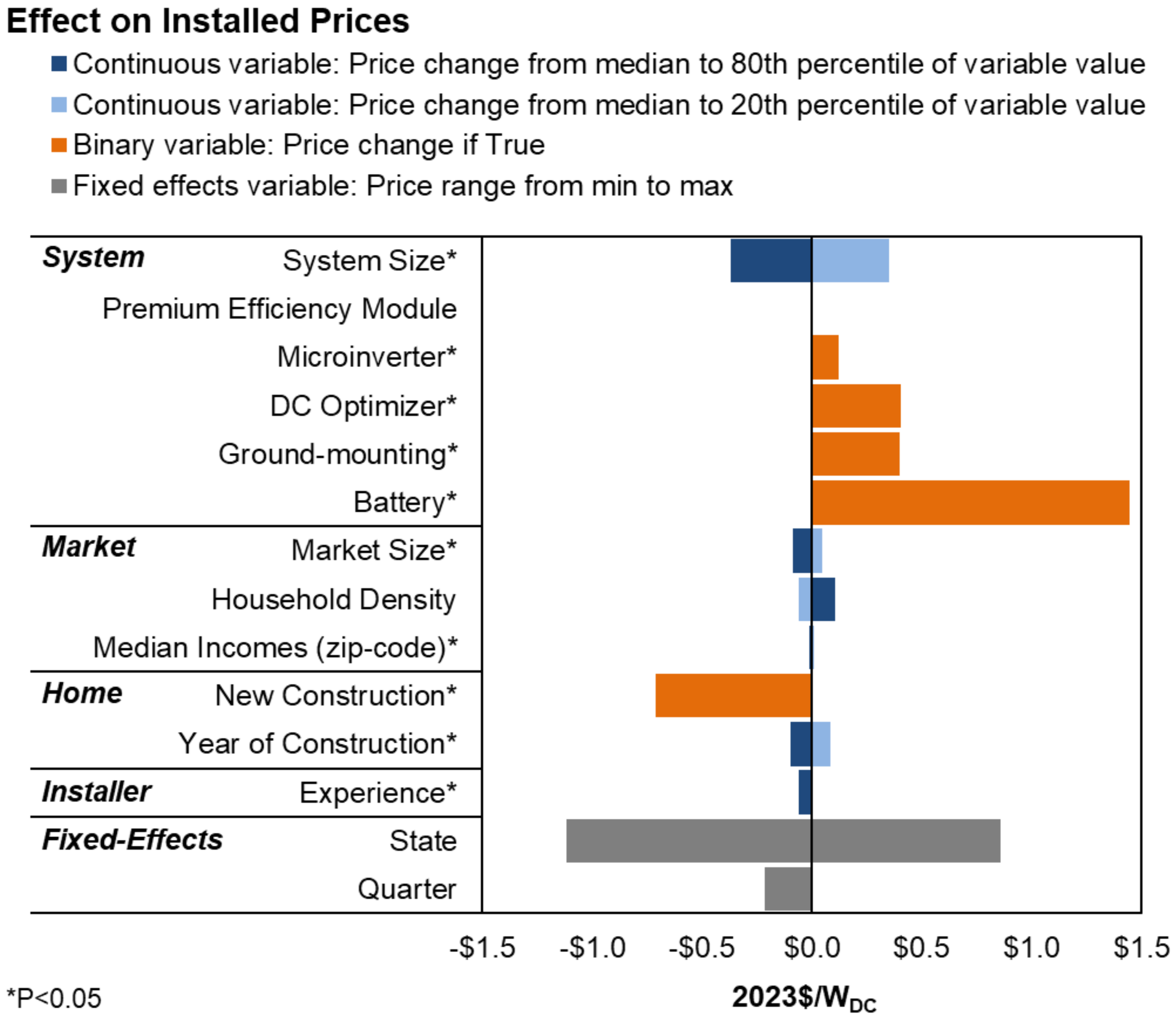
* $p<0.05$

Notes: *For further details on the model specification and variable definitions, please* [Barbose et al. (2019)]().

Sensitivity of Installed Prices to Modeled Drivers

This figure provides a sense of scale for the relative contribution of each pricing driver to overall pricing variability

- 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 (which is uncommon) also 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, across the 20th to 80th percentile range)
- The wide range across the state fixed-effects variables ($2/W), suggests the presence of strong state-level pricing drivers beyond those explicitly captured in the model

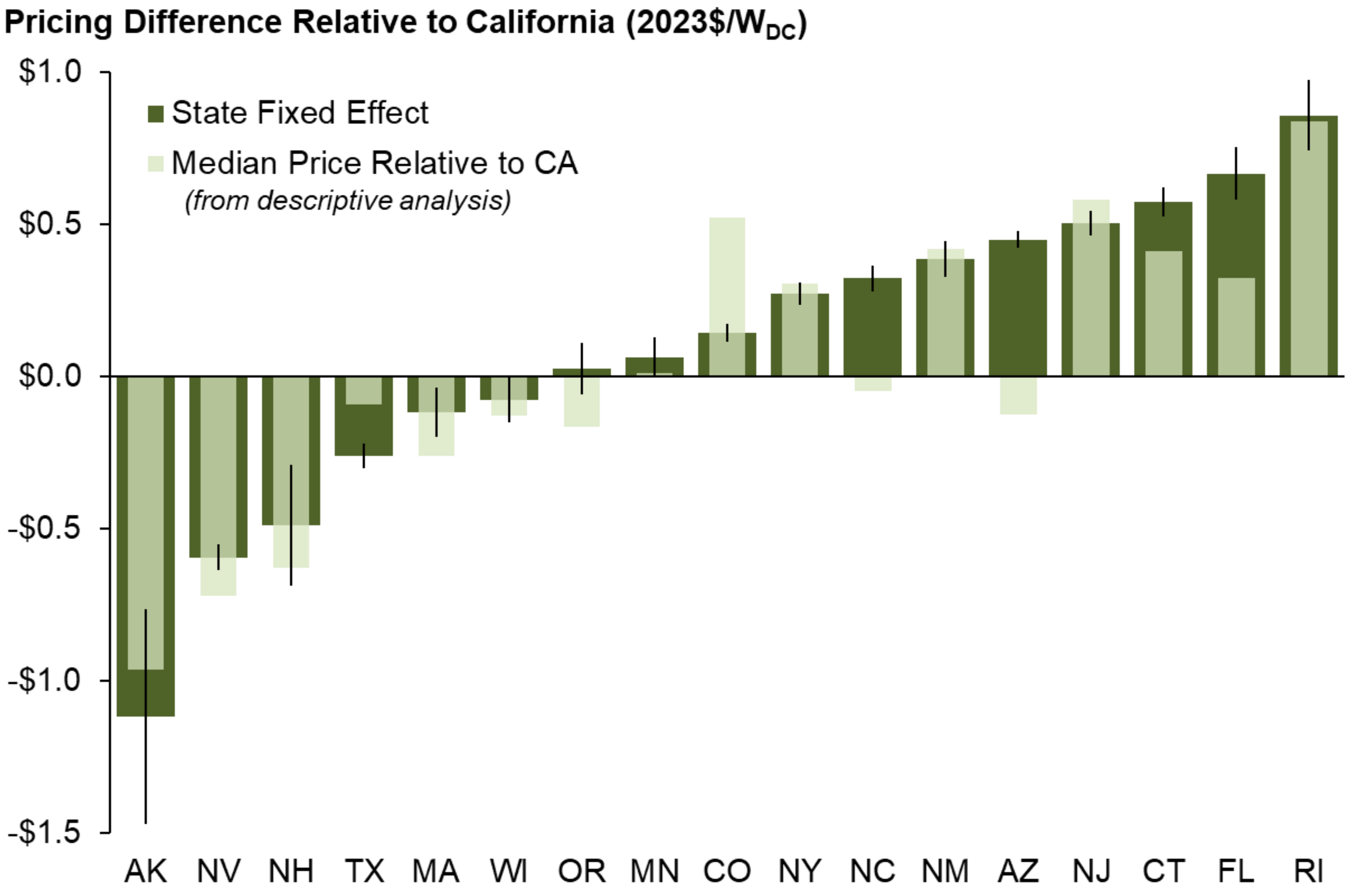


Notes: *For continuous variables, the figure shows the effect on system prices associated with moving from the median to the 20th percentile and from the median to the 80th percentile values of each variable. For binary variables, the figure shows the effect if that binary variable is true, and for fixed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

State Fixed-Effects

Residual Pricing Differences After Controlling for Other Factors

State Fixed Effects Compared to Difference in Median Prices



- State fixed effects represent the difference in average residential price, relative to California, after controlling for other variables
- Across most states shown, fixed effects range within a band of roughly ±$0.5/W from California, reflecting additional unexplained differences across states (e.g., cost-of-living, retail rates, incentives, solar insolation, permitting processes, etc.)
- In some states (particularly relatively small markets), fixed effects can also reflect idiosyncratic features of the data or how it is reported
- Fixed effects may be larger or smaller than the simple difference in state median prices, and may even point in different directions

For more information

Download the report, data, and other related materials:
http://trackingthesun.lbl.gov

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Appendix

List of Entities Contributing Data

AK Alaska Center for Energy and Power*
AR State Energy Office
AZ Ajo Improvement Company
AZ Arizona Public Service*
AZ Duncan Valley Electric Cooperative
AZ Mohave Electric Cooperative
AZ Morenci Water and Electric
AZ Navopache Electric Cooperative
AZ Salt River Project*
AZ Sulfur Springs Valley Electric Cooperative
AZ Trico Electric Cooperative
AZ Tucson Electric Power*
AZ UniSource Energy Services*
CA Center for Sustainable Energy (Bear Valley Electric)
CA Center for Sustainable Energy (PacifiCorp)
CA City of Palo Alto Utilities
CA Energy Commission*
CA Grid Alternatives*
CA Imperial Irrigation District
CA Los Angeles Department of Water & Power
CA Public Utilities Commission*
CA Sacramento Municipal Utility District
CO Xcel Energy/Public Service Company of Colorado*
CT Eversource*
CT Green Bank*
CT Public Utilities Regulatory Authority*
DC Public Service Commission*
DE Dept. of Natural Resources and Env. Control*
FL Energy & Climate Commission
FL Gainesville Regional Utilities*
FL Orlando Utilities Commission*
HI County of Honolulu (via Ohm Analytics)*
IL Dept. of Commerce & Economic Opportunity
IL Illinois Power Agency*
MA DOER*
MA Clean Energy Center
MD Energy Administration*
ME Avangrid*
ME Efficiency Maine
ME Versant*
MN Department of Commerce
MN Xcel Energy/Northern States Power*
NC Sustainable Energy Association*
NH Public Utilities Commission*
NJ Board of Public Utilities*
NM Energy, Minerals & Natural Resources Dept.*
NM Public Service Company of New Mexico*
NM Xcel Energy*
NV NV Energy*
NY State Energy Research and Development Authority*
OH Public Utilities Commission*
OR Energy Trust of Oregon*
OR Department of Energy*
OR PacifiCorp
PA Dept. of Community and Economic Development
PA Department of Environmental Protection
PA Sustainable Development Fund
RI Rhode Island Energy*
RI Commerce Corporation*
TX Austin Energy*
TX CenterPoint*
TX CPS Energy*
TX Frontier Associates
TX Oncor*
UT Office of Energy Development*
VA Dept. of Mines, Minerals and Energy
VT Energy Investment Corporation
VT Green Mountain Power*
VT Public Service Commission*
WA Puget Sound Energy*
WA Washington State University
WI Focus on Energy*

**denotes active data providers*

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