Title

Tracking the Sun: Pricing and Design Trends for Distributed Photovoltaic Systems in the United States, 2023 Edition

Authors

Barbose, Galen
Darghouth, Naim
O'Shaughnessy, Eric
et al.

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Tracking the Sun

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

2023 Edition

Galen Barbose, Naïm Darghouth,
Eric O'Shaughnessy, and Sydney Forrester
Lawrence Berkeley National Laboratory

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trackingthesun.lbl.gov

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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 2022
- 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 2022

Accompanying Data Products
available at trackingthesun.lbl.gov

1. **Summary brief:** 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
4. **Summary tables:** All figures and underlying summary tables are available in a MS Excel workbook

** 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.*

Report Structure

Data Sources, Methods, and Market Coverage

Data Sources

Tracking the Sun **relies on project-level 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
- Supplementary data from building permit records provided by Ohm Analytics, used in trends on storage attachment rates

70 entities spanning 30 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 2022 come from 44 organizations in 26 states

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

Units

- Real 2022 dollars (unless otherwise noted)
- Direct-current Watts (W_{DC}), unless otherwise noted

Installed Price: Up-front price (2022\$/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

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.*

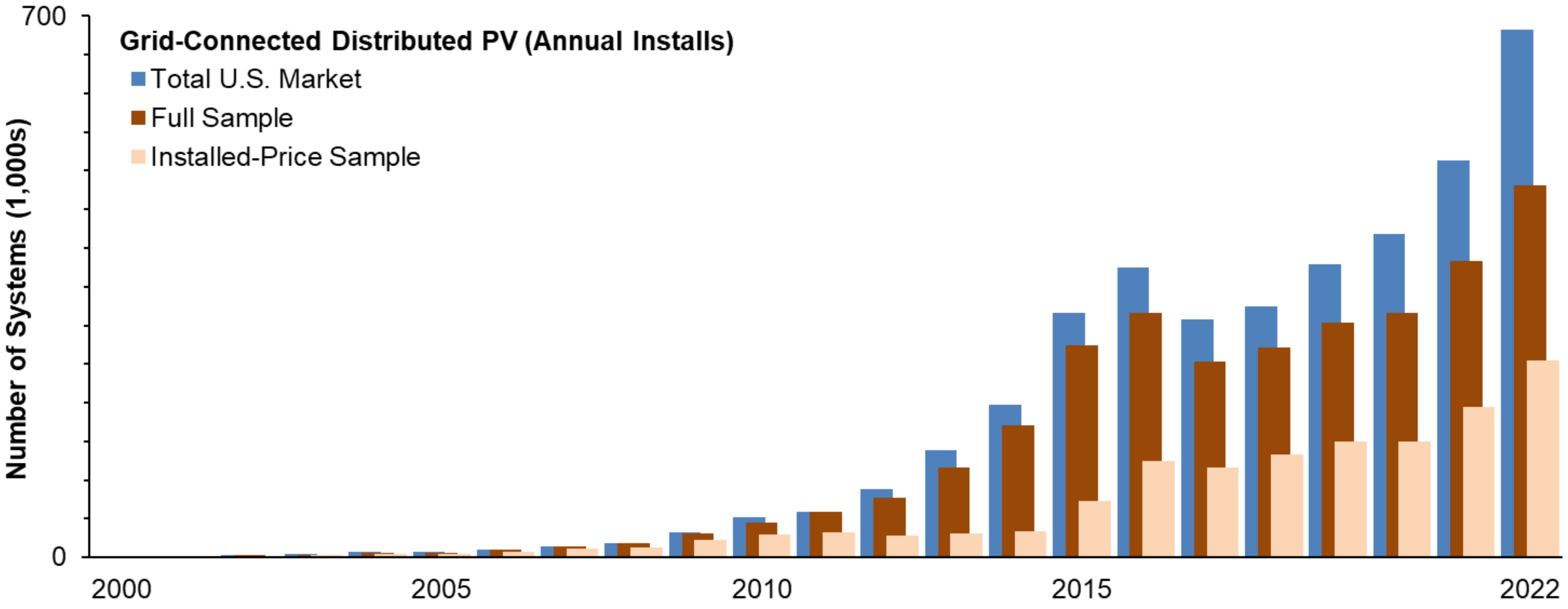
Sample Size Relative to Total U.S. Market

Full Sample

- **3.2 million** systems through 2022 (81% of U.S. market)
- 500,000 systems installed in 2022 (73% of U.S. market)

Installed-Price Sample

- **1.5 million** systems through 2022
- 250,000 systems installed in 2022



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.

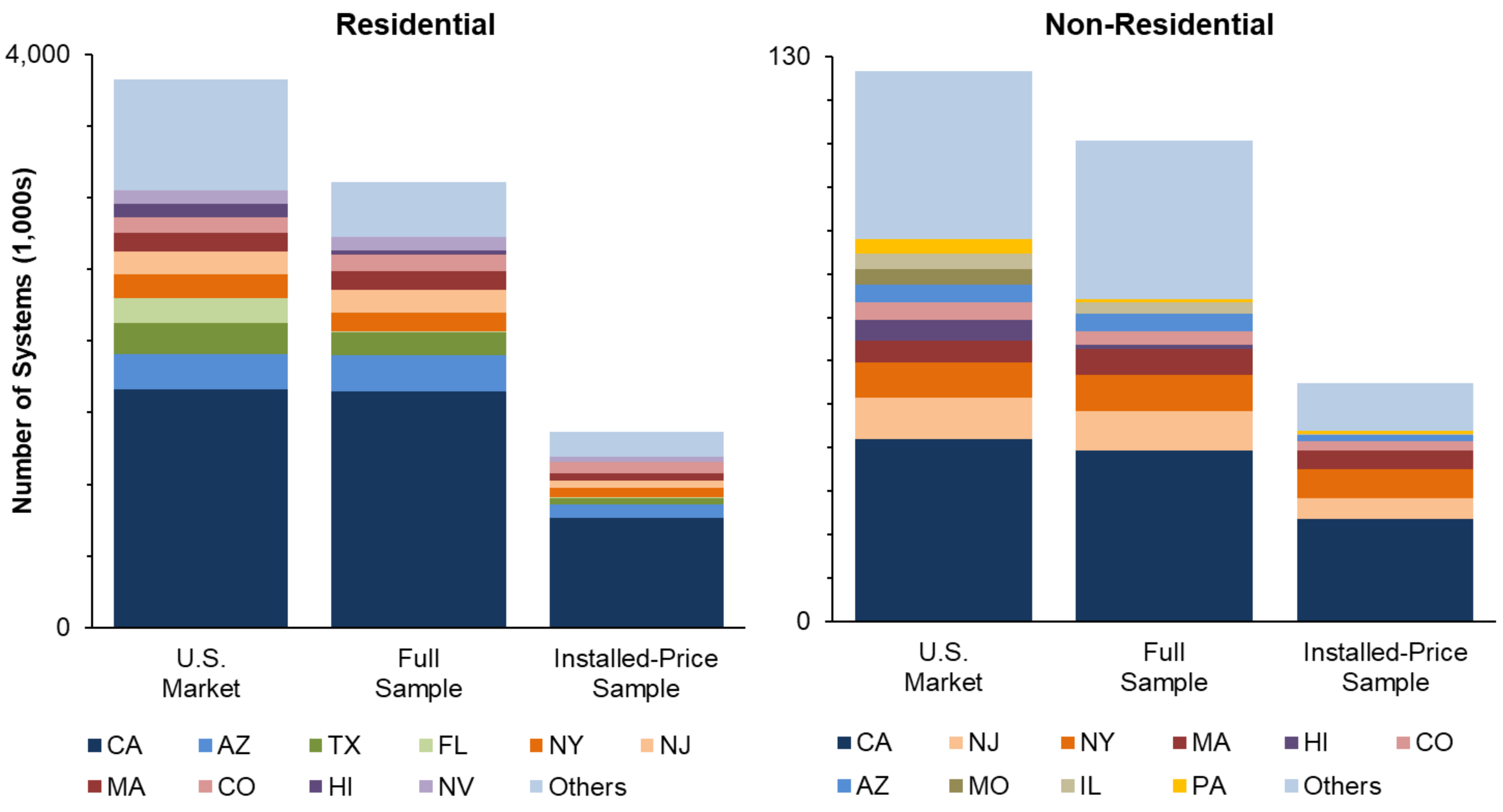
State-Level Sample Distribution and Market Coverage

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 Installs through 2022 (thousands)

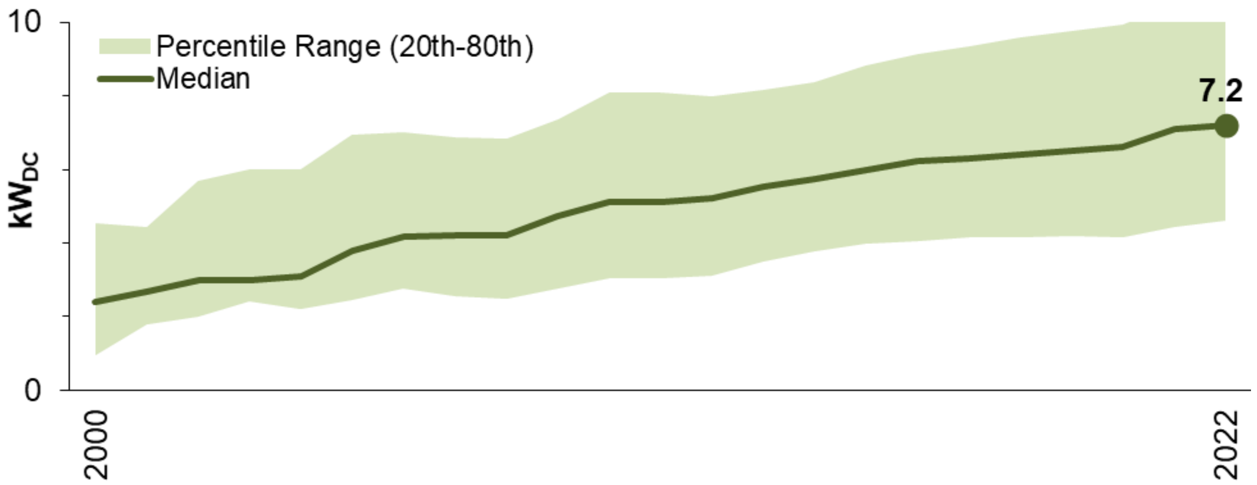


Notes: Data for the total U.S. market are from Wood Mackenzie's 2022 Year-in-Review "Solar Market Insight" report The figures show the top-10 states in each customer segment, based on cumulative U.S. installations through 2022, and all other states are combined in the "Other" category.

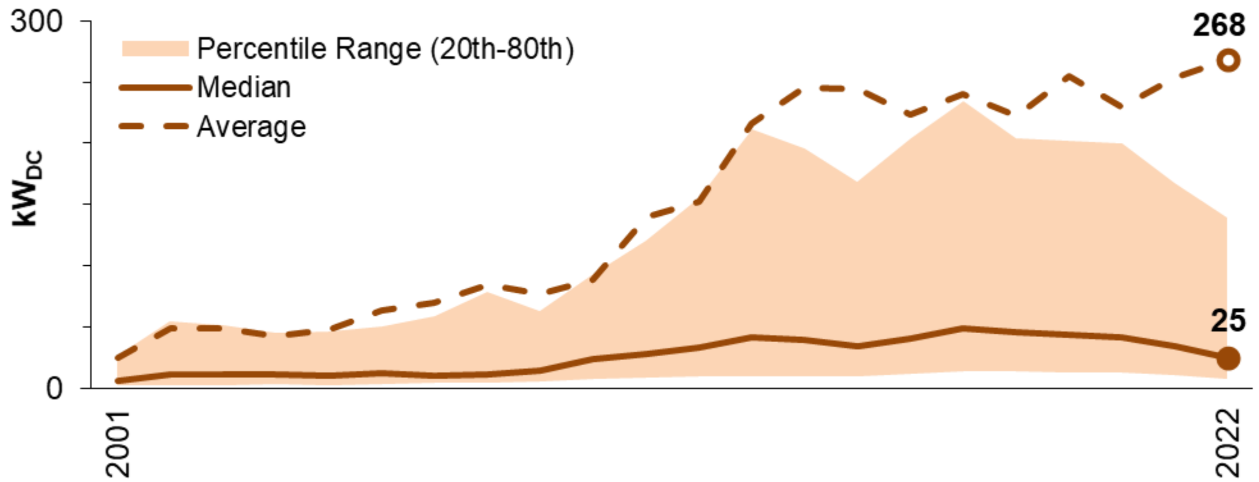
PV System Characteristics

System Size Trends

Residential System Size Time Trends



Non-Residential System Size Trends

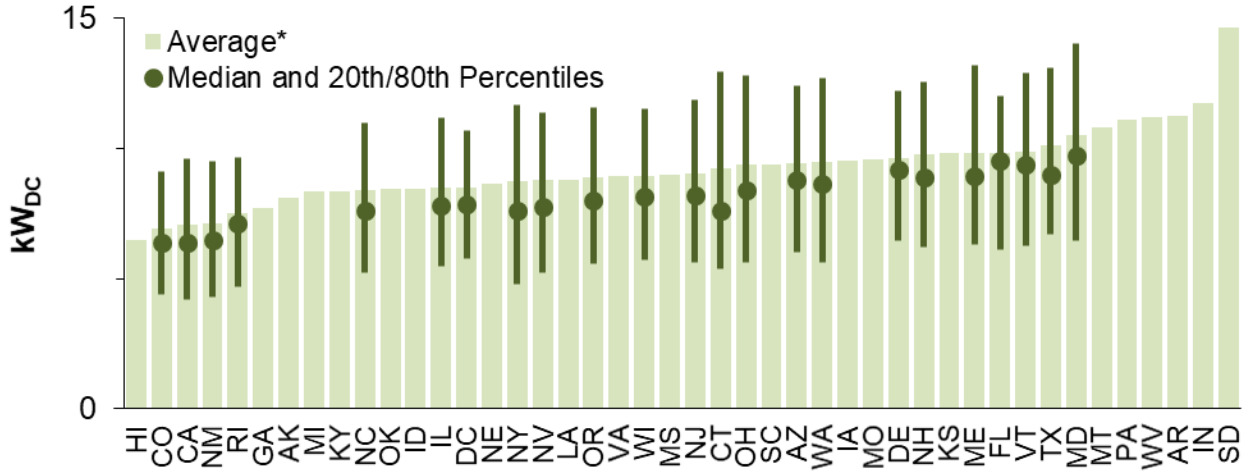


- Residential system sizes have been rising steadily over the past two decades, driven by declining costs and rising module efficiencies, among other factors
- Median residential system sizes reached 7.2 kW in 2022, with most systems ranging from 5-11 kW in size (the 20th to 80th percentile band)
- Non-residential system sizes vary widely (ranging from roughly 10-100 kW between the 20th-80th percentiles),
- Distribution has a long upper tail: median of 25 kW vs. average size of 268 kW in 2022
- 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)

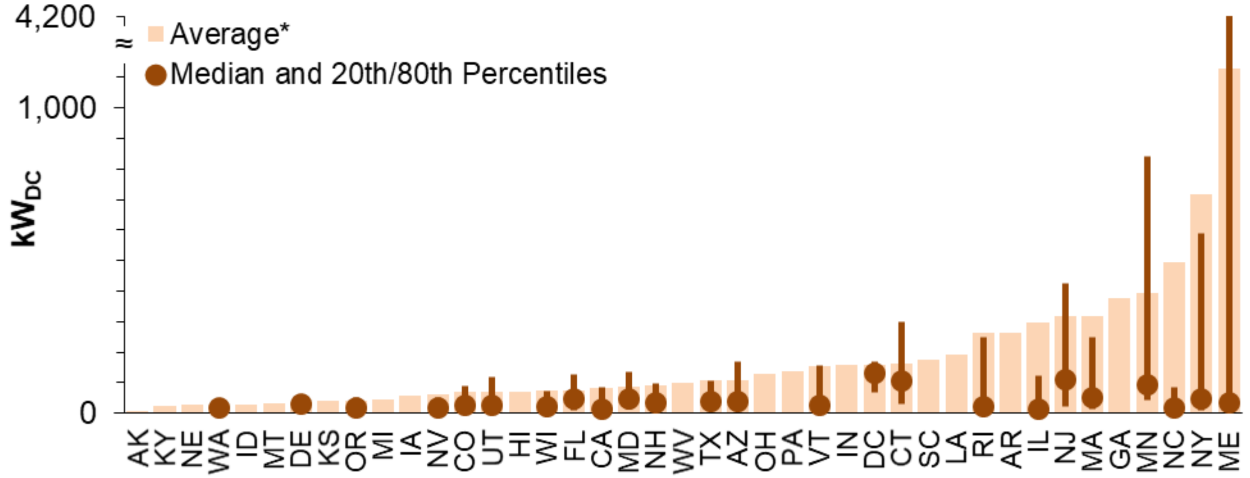
Notes: Summary statistics for any given year are shown only if at least 20 observations are available.

System Size Comparisons by State

Residential System Sizes by State (2022)



Non-Residential System Sizes by State (2022)

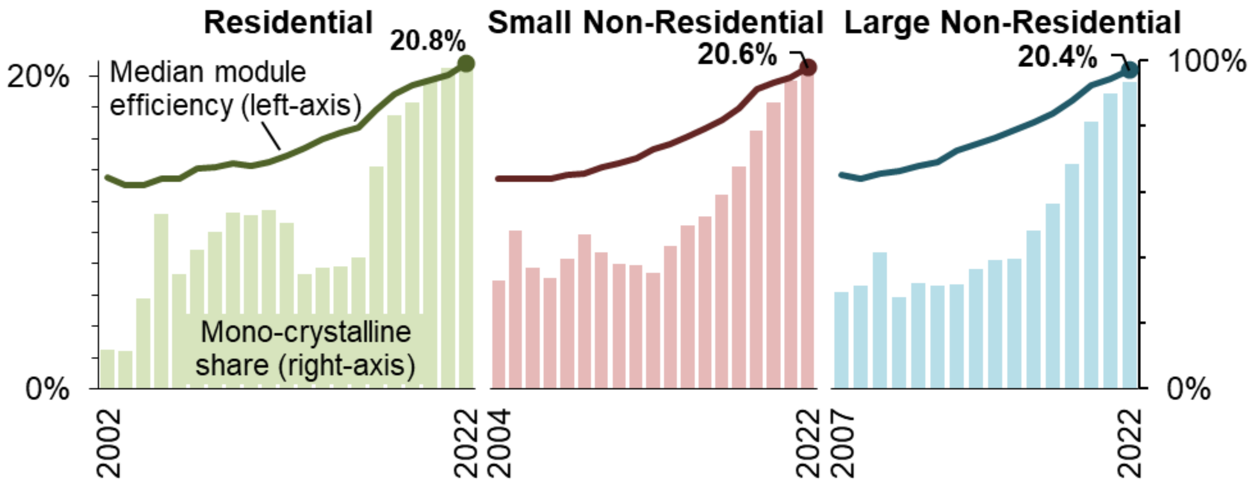


- Residential system sizes vary across states, reflecting regional factors such as electricity usage and insolation levels, among other factors
  - System sizes in California (7.1 kW) are near the low end of the spectrum, pulling the U.S. median downward
  - Median sizes in most states are well above 8 kW, and in many states above 9 kW
- State-level differences in non-residential system sizing are most notable at the upper tail of the distributions, which drives large differences in average sizes
  - States on the right-hand side all had a relatively significant share of large systems (e.g., large contingents of community solar projects in MN and ME)
  - In most states, the majority of non-residential systems installed in 2022 were <100 kW

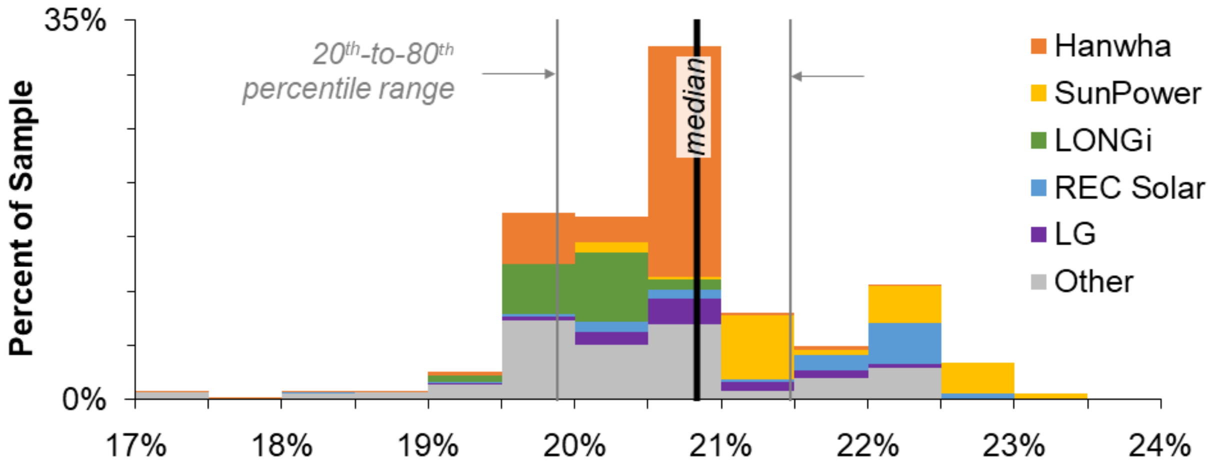
*Notes: *Averages are derived from project level data where available, and in the case of residential systems are calculated from systems <40 kW, in order to exclude erroneous data and remove large agricultural or multi-family housing projects classified as residential. For states not in the Tracking the Sun dataset, averages are derived from state-level statistics published in the annual "Solar Market Insight" report published by Wood Mackenzie and SEIA; 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 Time Trends by Customer Segment



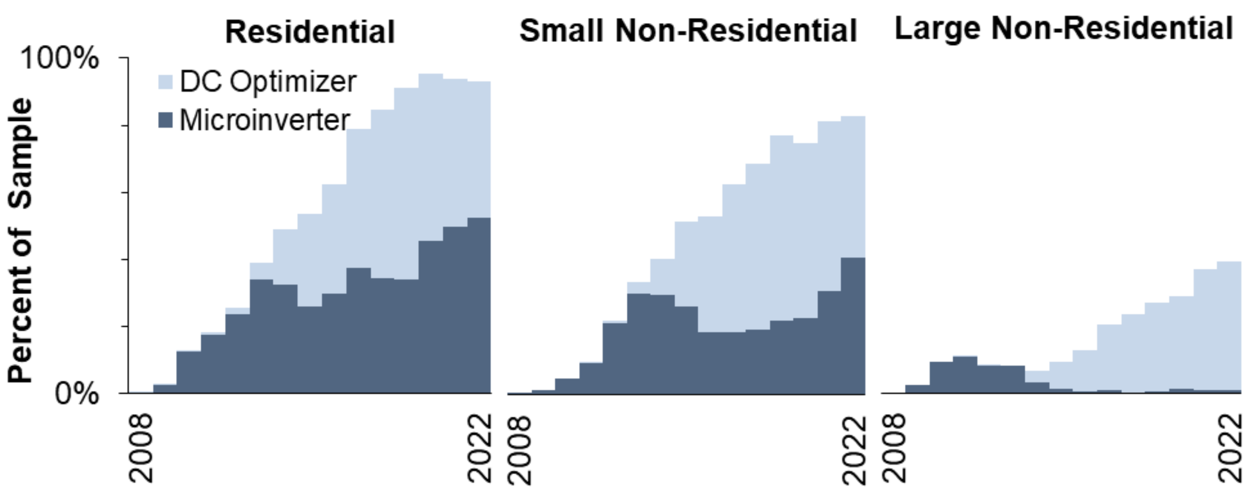
Module Efficiency Distribution by Manufacturer (2022)



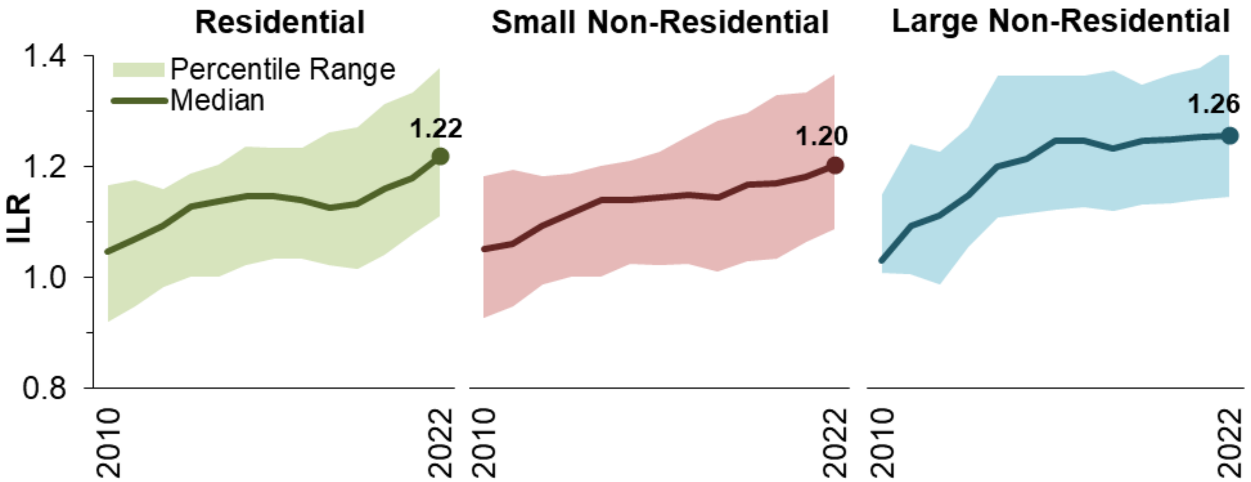
- Higher module efficiencies allow for denser installations and can enable reductions in those soft costs and balance of system costs that scale with square footage
- Module efficiencies have risen steadily over time across all customer segments, with slightly higher efficiencies in the residential segment
- Long-term increase in median module efficiencies partly reflect sharp increase in market share of mono-crystalline modules, among other factors
- Module efficiencies vary considerably: most systems installed in 2022 fall within a range of 20% to 21.5%, varying to some extent by manufacturer; several specialize in “premium-efficiency” models (>22%)

Inverter Technology Trends

Microinverter and DC Optimizer Trends



Inverter Loading Ratios (DC-to-AC Ratio)

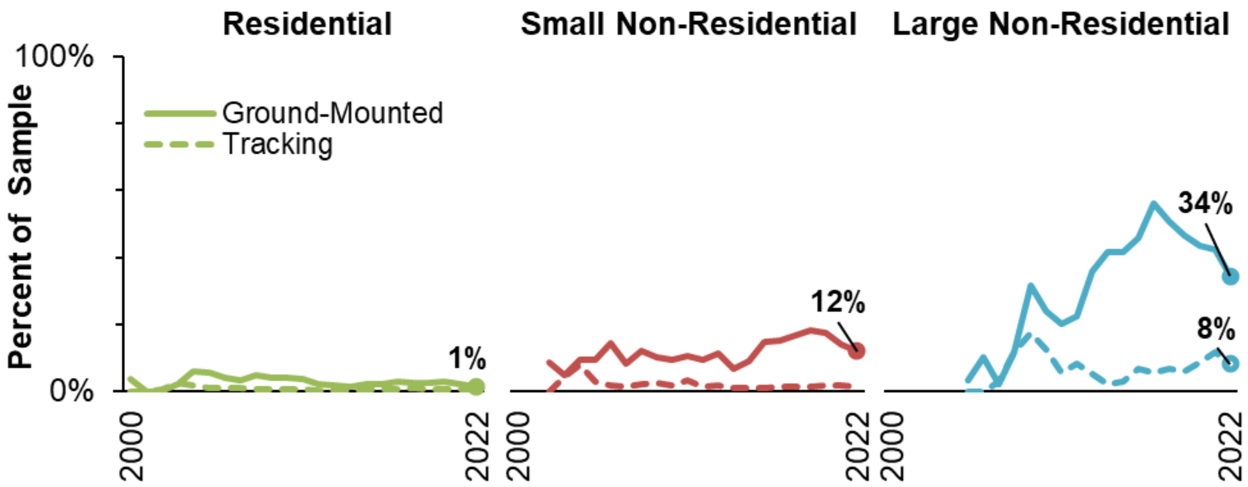


- Module-level power electronics (MLPEs), which include both microinverters and DC optimizers, have continued to gain share across the sample
- MLPEs are almost universal within the residential and small non-residential sectors (93% and 83% of 2022 installs, respectively); less common for large non-residential (39%), but optimizer-share growing steadily
- DC optimizers dominate MLPE growth since 2013, but microinverter share has been rising in recent years
- 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

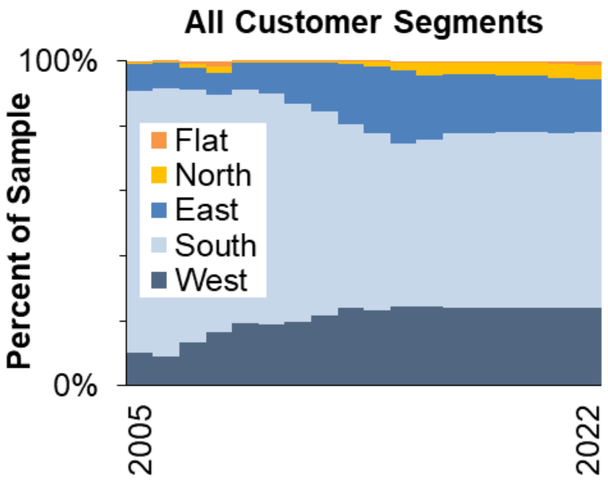
Notes: DC Optimizer share is based only on systems with SolarEdge inverters, as those are the only records in the dataset for which the presence of DC optimizers can be determined. As a result, the DC optimizer share shown in the figures may understate the actual share of power optimizers in the data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

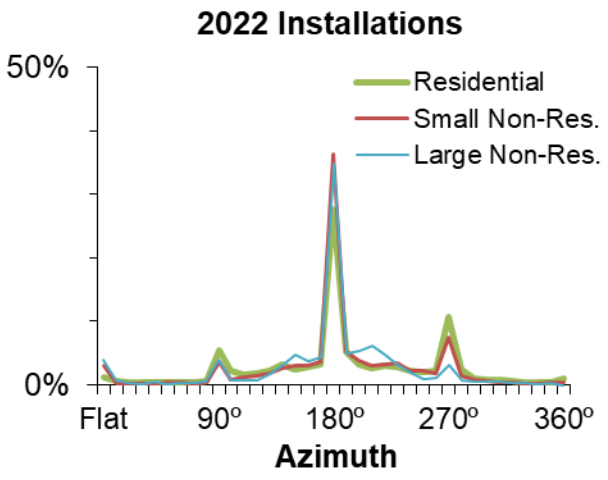
Mounting Configuration and Panel Orientation

Ground-Mounting and Tracking Equipment (2022)



Panel Orientation





- Ground-mounting (as opposed to roof-mounting) is most prevalent among large non-residential systems, while use of tracking is limited
  - Roughly one-third (34%) of large non-residential systems in 2022 are ground-mounted, while 8% 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
  - 54% of systems installed in 2022 face south, 24% 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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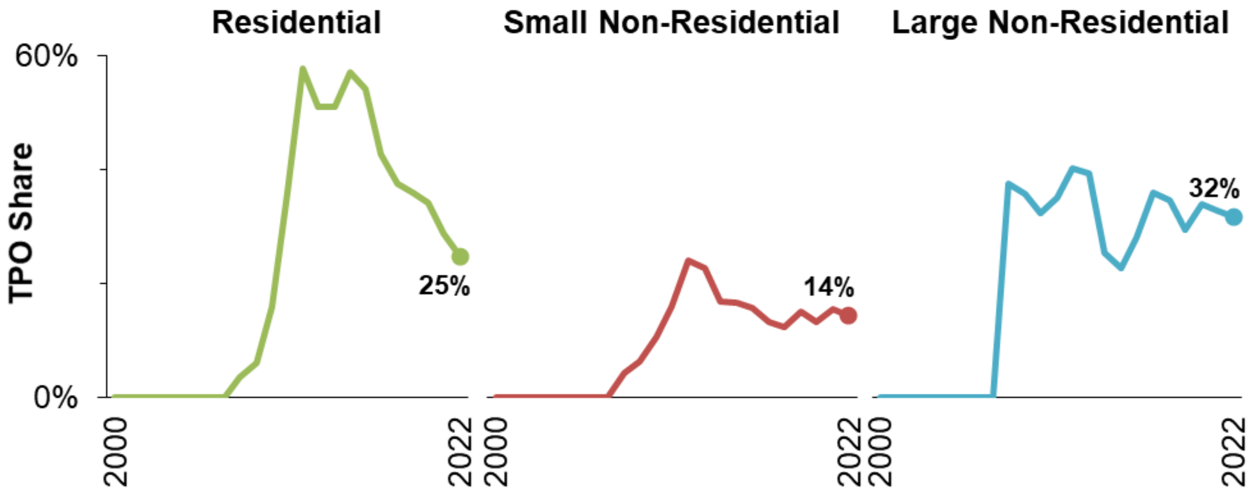
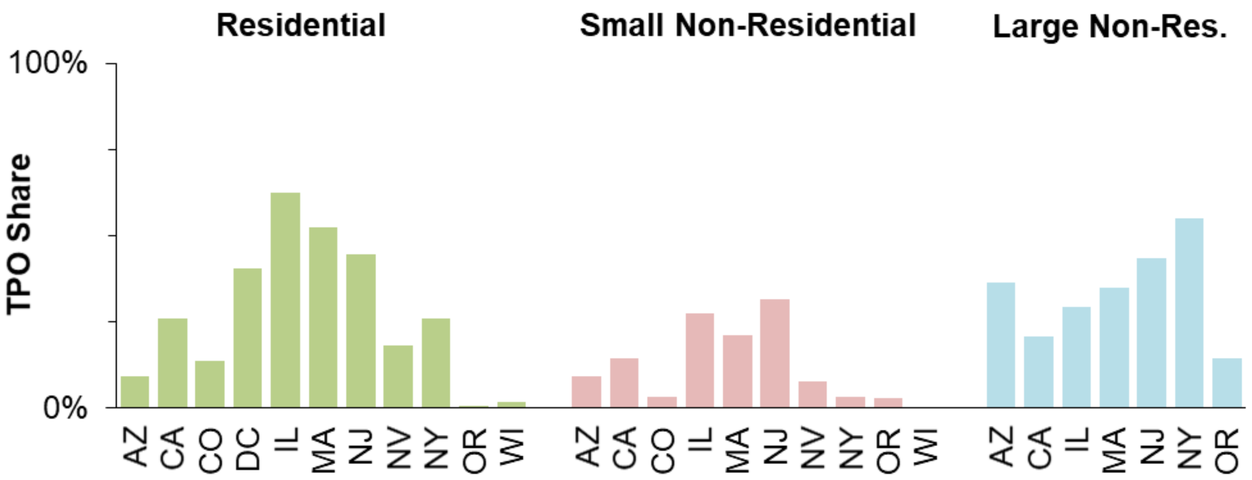
Notes: Summary statistics for any given year are shown only if at least 20 observations are available. Figures in the bottom panel exclude tracking systems, and in both figures, the orientation is based on the primary array (for systems with multiple arrays facing different directions). For the figure 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.

Third-Party Ownership Trends

Third-Party Ownership Trends



Third-Party Ownership by State (2022)

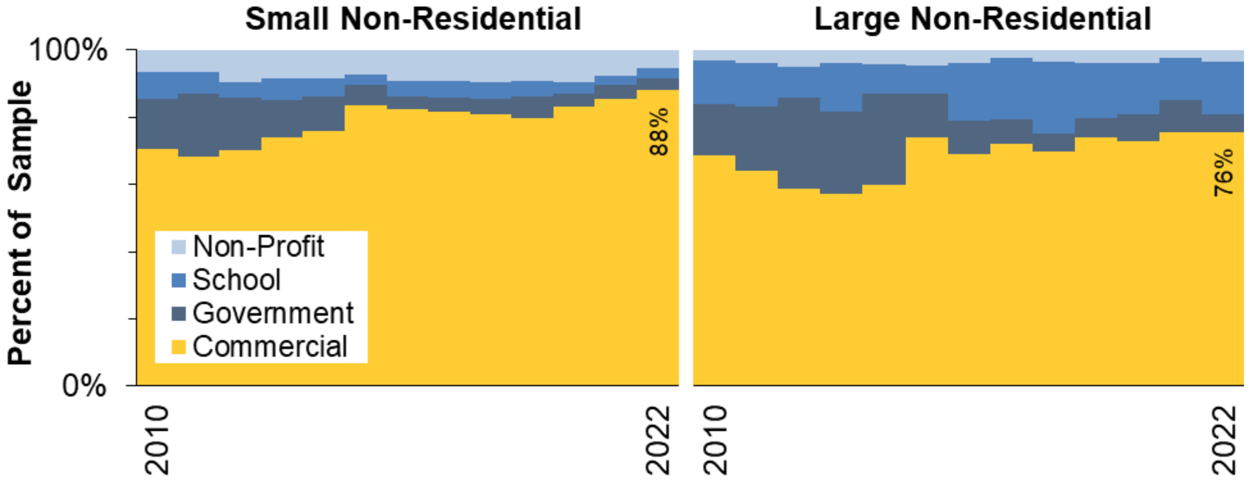


- Third-party ownership (TPO) in the residential sample has declined over time from its historical high of ~60% in 2012 to 25% in 2022
  - Reflects emergence of residential loan products
- For the non-residential sample, TPO shares have remained comparatively steady and have historically been lower for small vs. large non-residential systems
- TPO shares at the state level vary substantially
  - Generally higher among states with sizeable rebate programs or high solar renewable energy certificate prices (DC, IL, MA, NJ)
  - Some states limit TPO or restrict eligibility for incentive programs to only host-owned systems

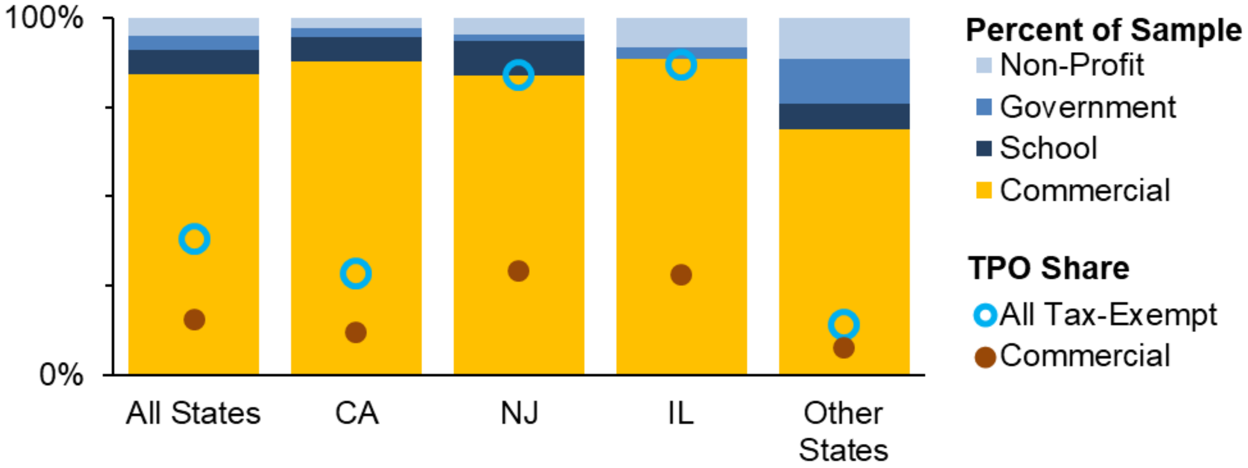
Notes: In the bottom figure, data are shown for individual states only if TPO status is available for at least 20 systems and for at least 50% of records for the given state, year, and customer segment. Furthermore, we exclude a number of states from the figure where the underlying data source may not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

Non-Residential Customer Segmentation

Non-Res. Customer Segmentation Trends over Time



Non-Res. Customer Segmentation by State (2022)



- For-profit commercial customers make up the vast majority of non-residential site hosts, with the remainder consisting of some combination of tax-exempt site hosts (schools, government, non-profits)
- Among tax-exempt site hosts, non-profits have been most prevalent within the small non-residential market, while schools and government facilities are more common within the large non-residential segment
- The overall mix of non-residential customer segments is similar across states, though tax-exempt tend to make up a larger share in smaller state markets
- TPO has been more prevalent among tax-exempt site hosts than for commercial hosts (38% vs. 16% in 2022), to monetize tax benefits, but direct-pay option under IRA may reduce this driver

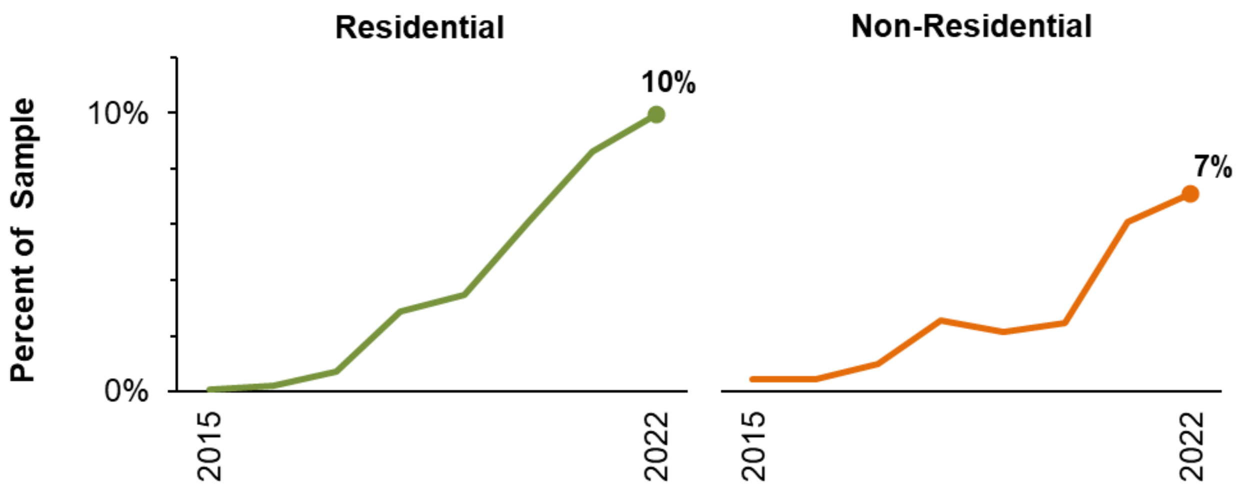
Notes: The figures are based on a subset of the non-residential records for which data on the specific subsegment are available. In the bottom figure, the four states shown are those with the most available data and are among the largest non-residential markets in 2022.

Paired PV+Storage System Characteristics

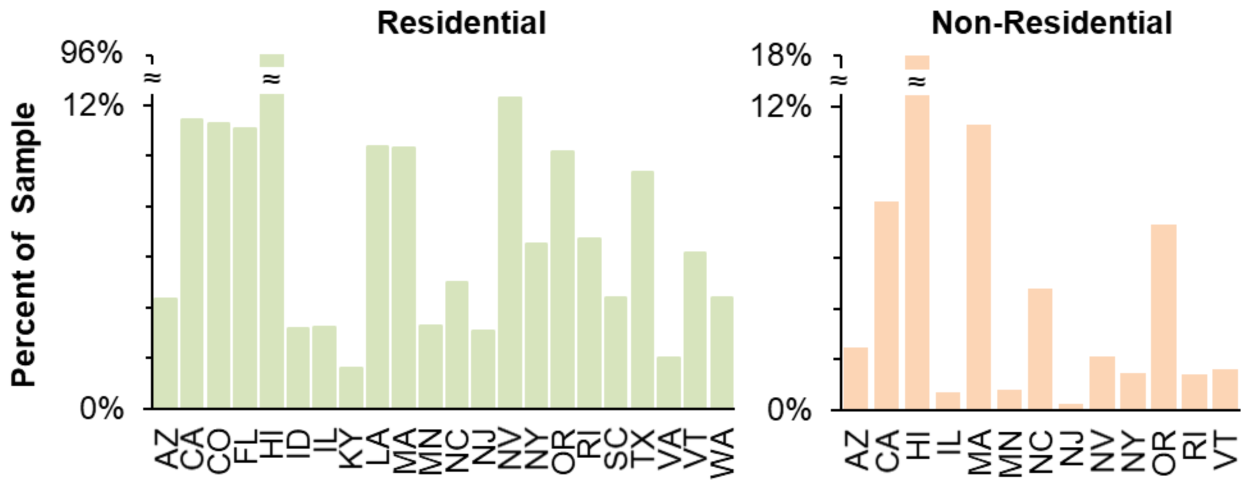
Storage Attachment Rates

Percent of PV systems installed each year with storage

Storage Attachment Rates over Time



Storage Attachment Rates by State (2022)



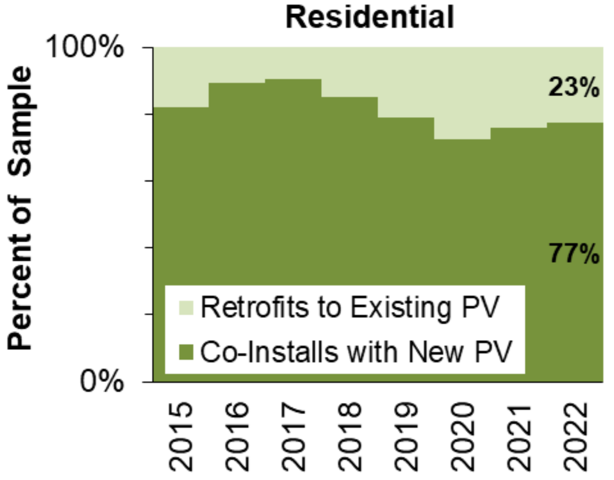
- Storage attachment rates have steadily risen over time, reaching 10% of the sample in 2022 for residential systems and 7% for non-residential
- HI has, by far, the highest residential attachment rates of any state (96% in 2022), driven in part by net metering reforms that incentivize self-consumption
- CA, which hosts the vast majority of paired systems, has attachment rates of 11% (res.) and 8% (non-res.), driven by storage rebates and resilience concerns
- Many states seeing ~10% residential attachment rates; most seeing at least 5%
- Non-residential attachment rates are more varied across states: several around 8-12%, but most others <2%; non-res. market more sensitive to economics and policy support

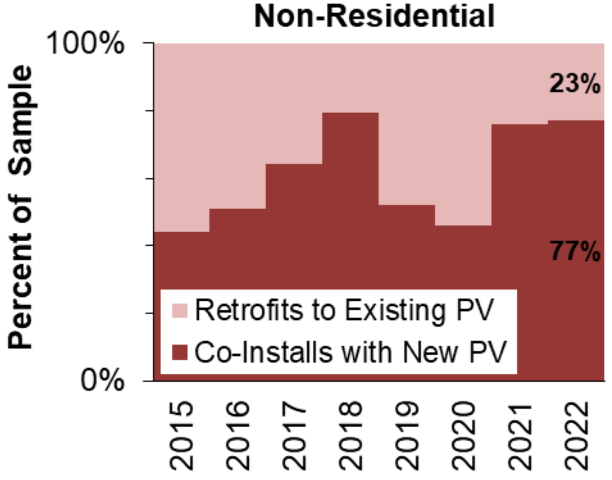
Notes: Attachment rates are based on a merging of Tracking the Sun and permit data from Ohm Analytics, allowing additional states to be covered. State-level attachment rates are shown only if available data cover at least 50% of the state market volume. Note the breaks in the y-axes for Residential and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

Storage Retrofits to Existing PV Systems

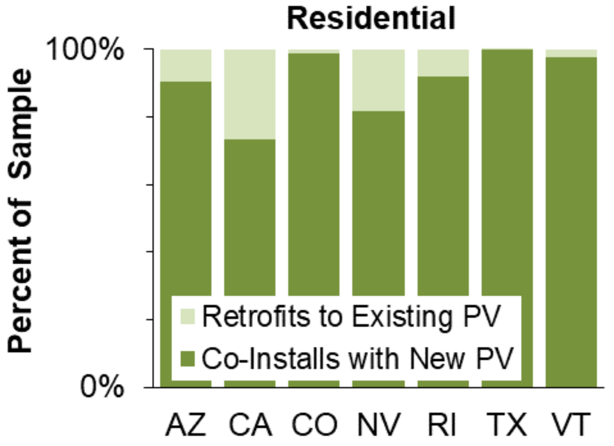
Based on a subset of the dataset

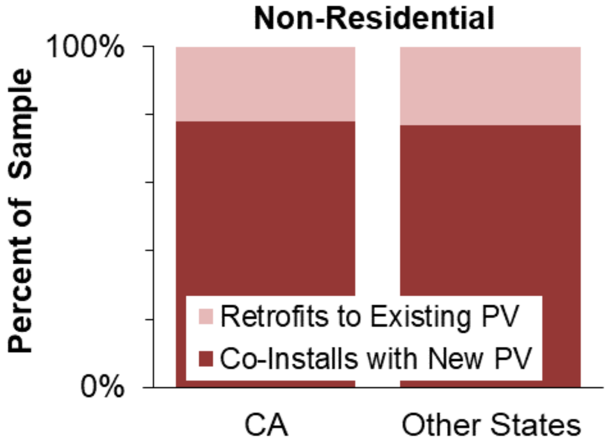
Retrofits vs. Co-Installs by Year





Retrofits vs. Co-Installs by State (2022)





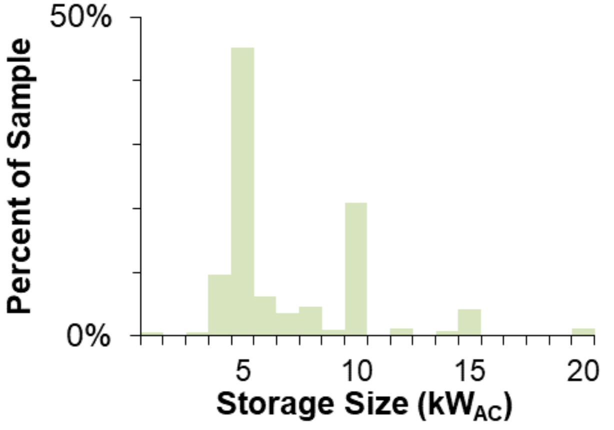
- Attachment rates capture only new systems; storage is also often retrofitted onto existing PV systems
- Storage retrofits represented 23% of new storage installs paired with PV in 2022, in both the residential and non-residential markets
- Within the residential market, retrofits are particularly common in California (26% of new paired storage installs in 2022), driven by resilience concerns and TOU pricing
- For the non-residential market, retrofit rates are similar between California and other states (see Notes)
- In about half of all cases, storage retrofits are also accompanied by additional PV capacity, on top of the existing PV system

Notes: The figures are based on only the subset of states for which storage retrofits can be reliably identified within the dataset, which are listed in the figure on the lower left. For the figure on the lower right, all states with available data other than California are aggregated together, due to small sample sizes.

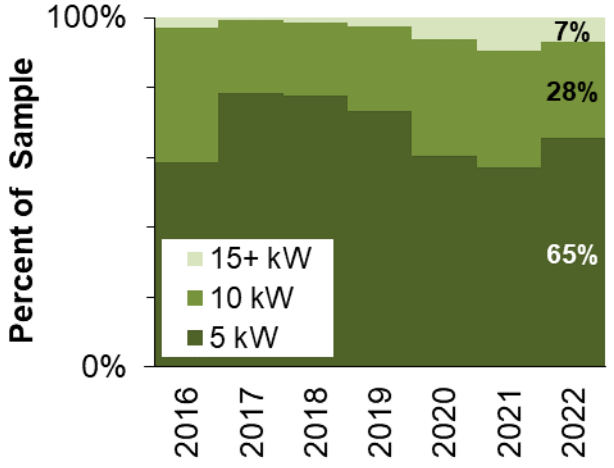
Residential Paired System Sizing

Storage Size Distribution

Systems Installed in 2022

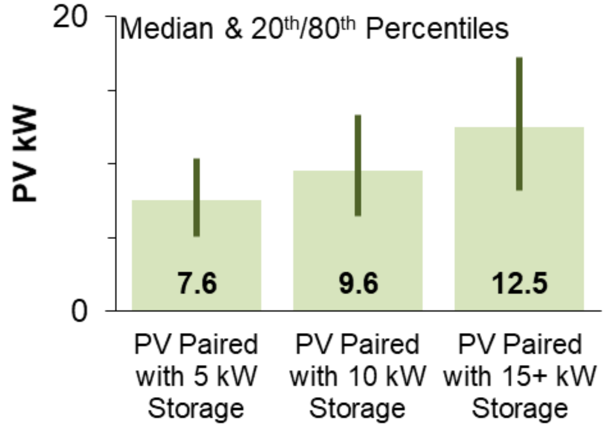


Storage Size Trend



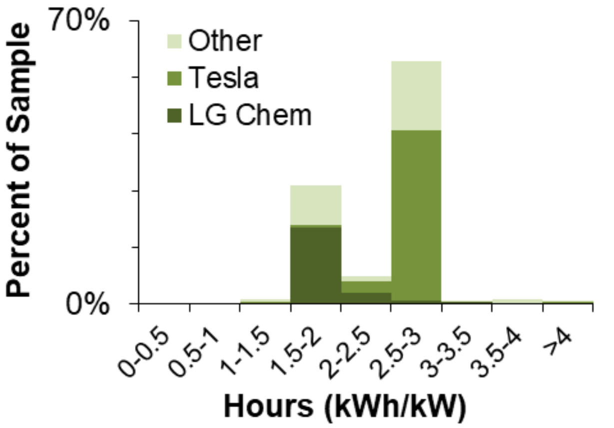
PV Sizing with Storage

Systems Installed in 2022



Storage Duration

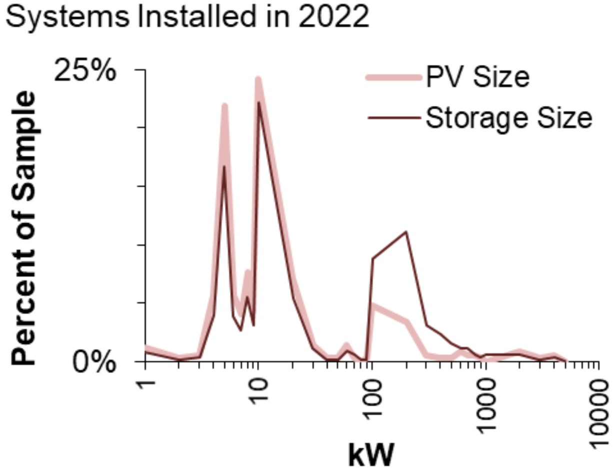
Systems Installed in 2022



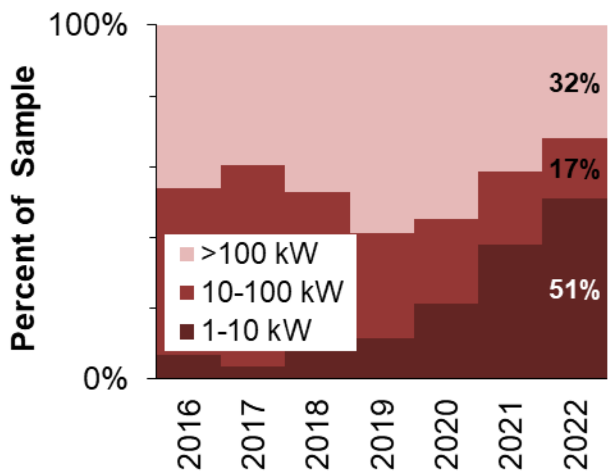
- Most residential storage systems paired with PV come in increments of 5 kW-storage
- The market has been trending toward systems with larger batteries, driven by backup power demand, though this reversed course slightly in 2022 (35% of paired systems installed in 2022 had 10+ kW of storage)
- Larger amounts of storage tend to accompany larger PV systems: e.g., median PV capacity of 12.5 kW for systems with 15+ kW of storage
- Typical residential storage duration reflects the two products that dominate market share: LG Chem RESU10H (1.9 hrs) and Tesla PowerWall (2.7 hrs)

Non-Residential Paired System Sizing

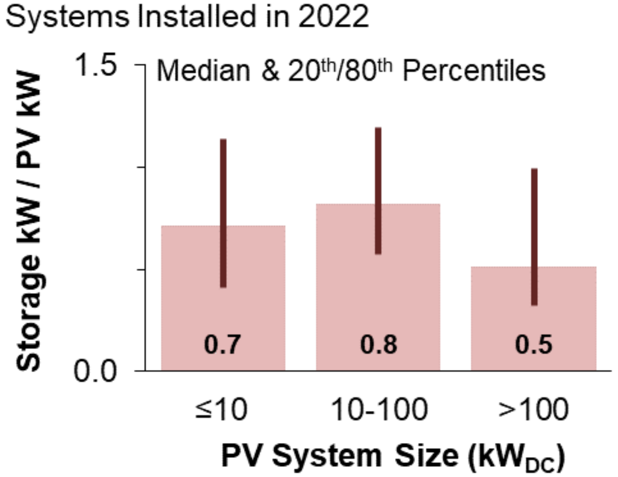
Size Distributions



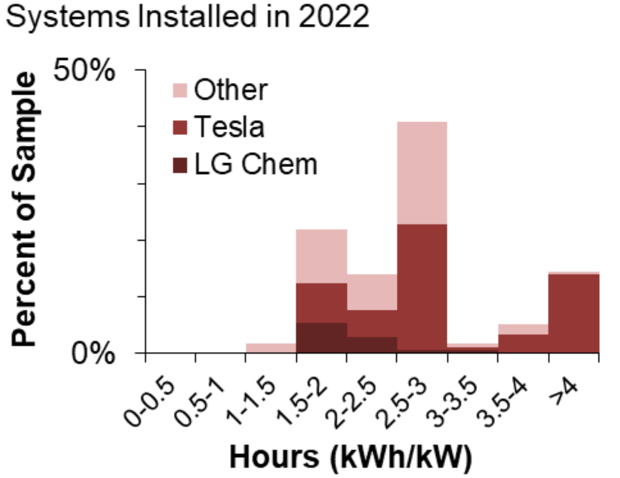
Storage Size Trends



kW Ratio: Storage to PV



Storage Duration



- Most paired non-residential systems installed in 2022 were relatively small, with PV and storage components both <20 kW; about 1/3rd were >100 kW
- Paired applications in the non-residential market have been moving into progressively smaller applications in recent years; no longer the exclusive domain of large users with high demand charges
- Most paired non-residential systems installed in 2022 have battery power ratings below the corresponding PV capacity (median kW ratio of 0.5-0.8, depending on the PV size range)
- As with residential, most non-residential systems installed in 2022 have storage durations ranging from 1.5-3 hours, though longer duration (4+ hours) are more common (mostly Tesla PowerPack)

Median Installed Price Trends

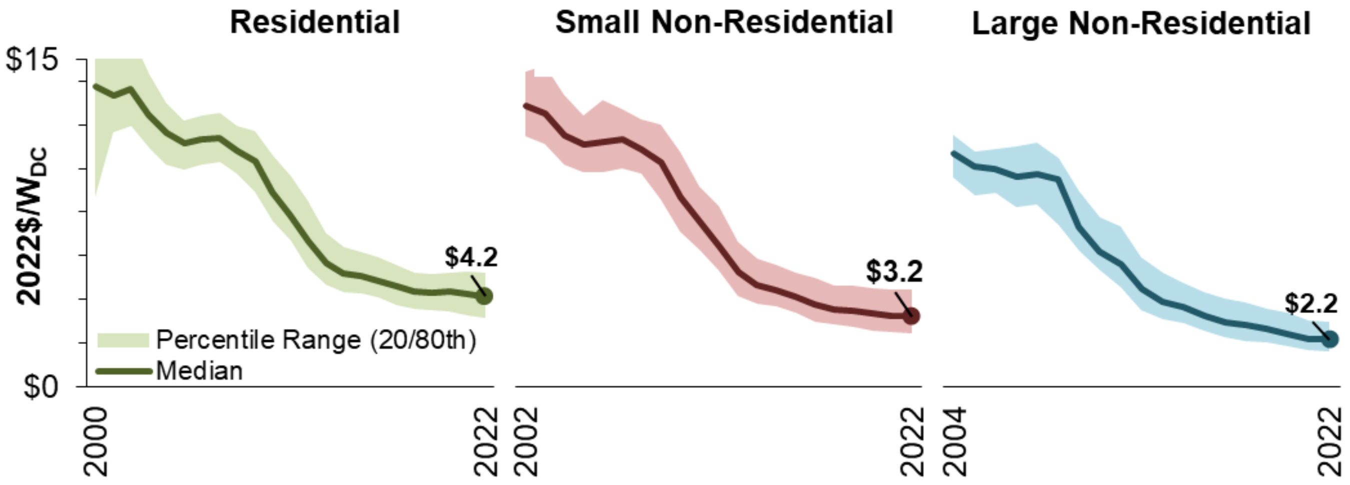
A Few Notes on Installed-Price Data

- Excludes third-party owned (TPO) and self-installed systems
- Data are self-reported by PV installers or customers
- Reported prices may include dealer fees for loan-financed systems (and other ancillary items related to the PV installation)
- Prices are adjusted for inflation, unless otherwise noted

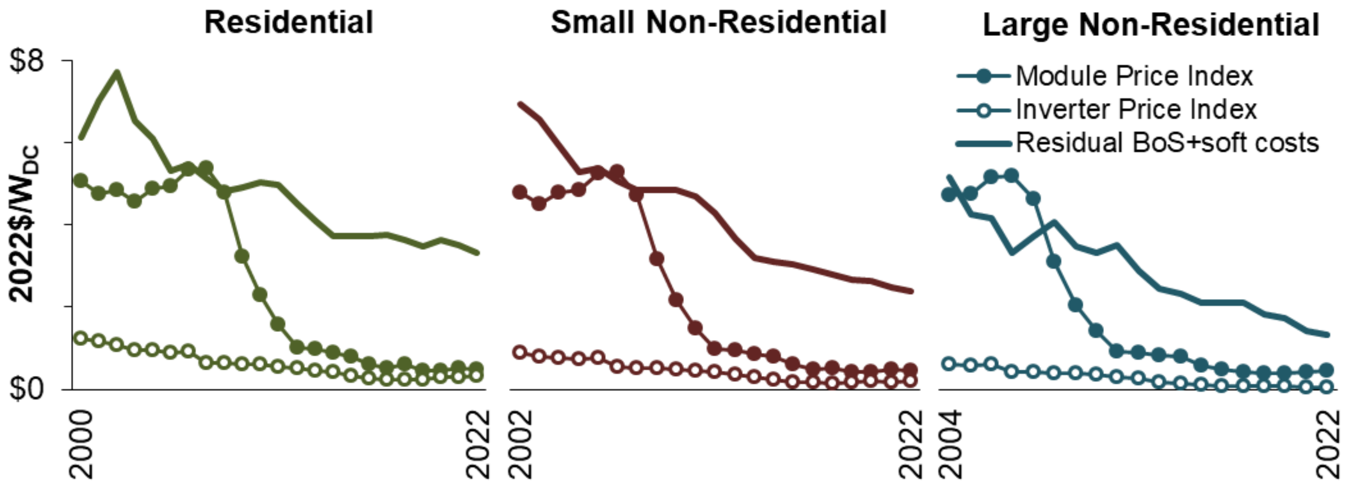
Long-Term Trends in Median Prices and Component Costs

Stand-alone PV systems

National Installed Prices over Time (Inflation-Adjusted)



Underlying Trends in Component Costs



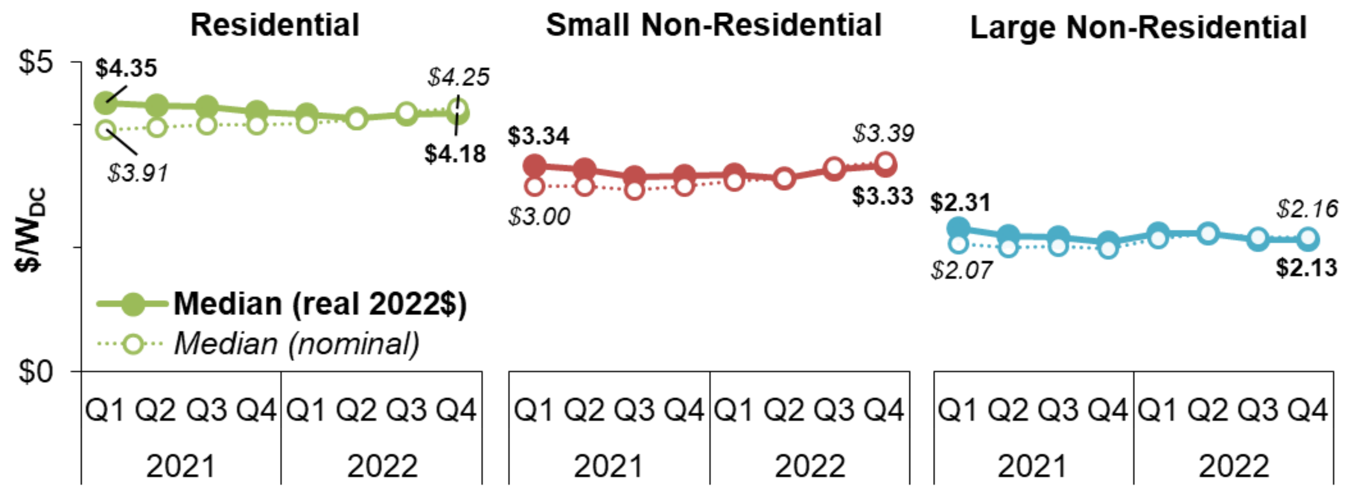
- Over the long-term, median installed prices have fallen (in real terms) by roughly $0.4/W per year, on average, but price declines tapered off starting in 2013, averaging $0.1-0.2/W per year since then
- That tapering off is mostly a function of the underlying trajectory of module costs, which fell 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 the aggregate set of “Residual BoS+soft costs,” which comprise the vast majority of overall system prices
- Over the long-term, those residual BoS+soft costs have, in aggregate, fallen at a relatively steady pace of $0.1-0.2/W per year, on average

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).

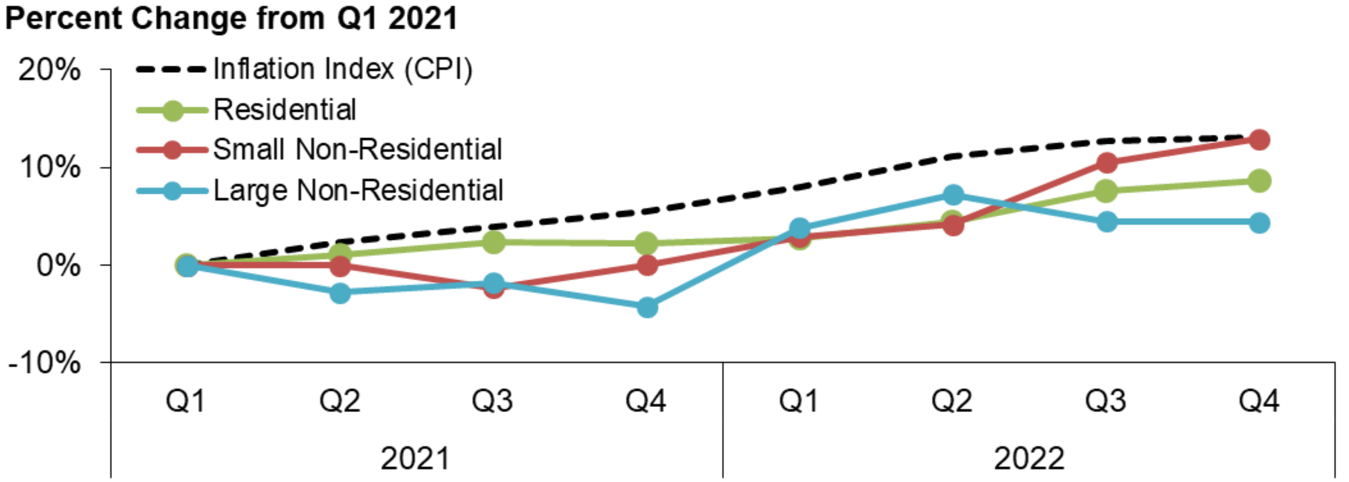
Recent Trends in Median Installed Prices (2021-2022)

Stand-alone PV systems

Quarterly Median Installed Prices: Real vs. Nominal



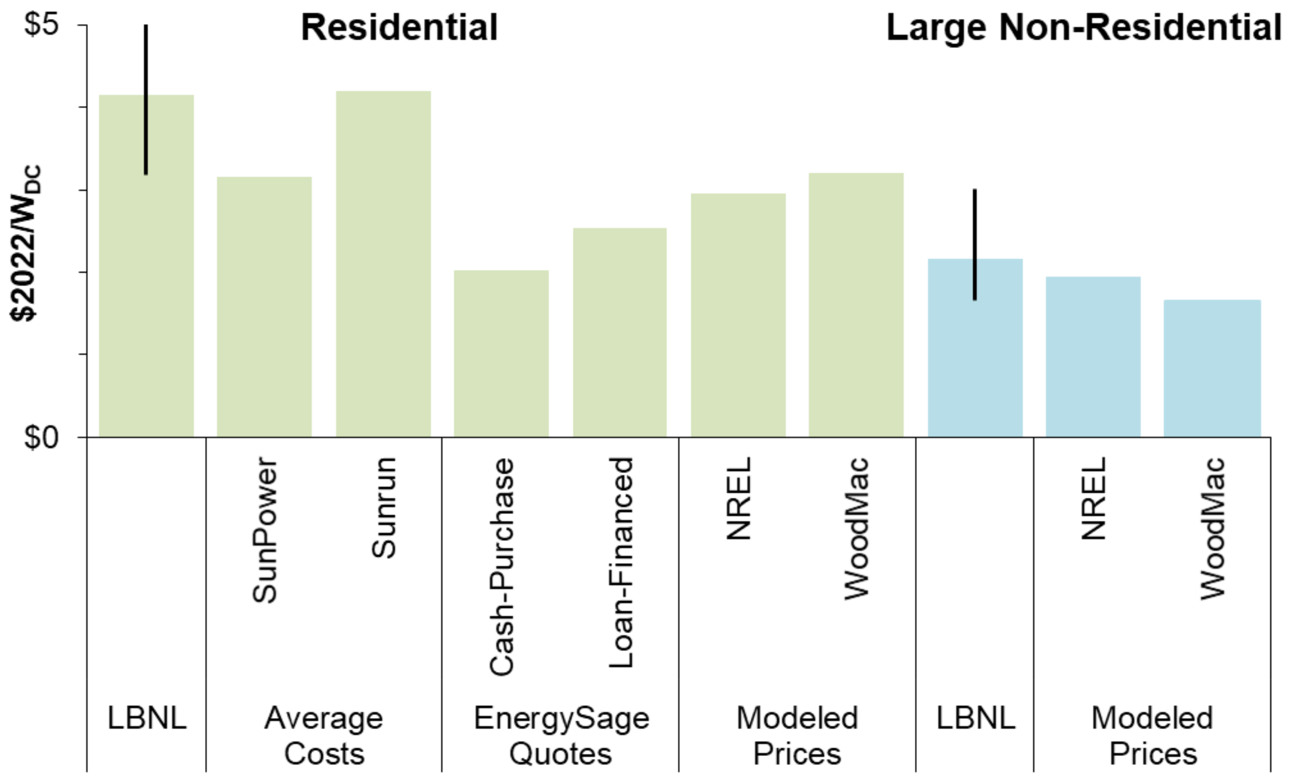
Nominal Price Trend Relative to Inflation



- Quarterly values are shown here, to provide more temporal resolution into trends over the last year of the analysis period
- In real (inflation-adjusted) dollars, median installed prices fell over this timeframe, by roughly $0.2/W for residential and non-residential systems, while remaining flat for small non-residential systems
- This is roughly in line with the average rate of price decline for the past decade
- In contrast, nominal prices—what market participants observe—rose by $0.1-0.3/W (or 4-13%), depending on the market segment, from Q1 2021 to Q4 2022
- Put differently, while nominal prices rose, that increase was generally slower than general inflation, which rose by 13% over this timeframe, based on the consumer price index (CPI)*

**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. The BLS also publishes CPI for only energy-related items, which rose at a much higher rate (35%) over the timeframe shown here. Another common index for inflation adjustments is Bureau of Economic Analysis' Implicit Price Deflators for Gross Domestic Product, which rose by 12% over the period presented here.*

Comparison to Other PV Cost and Pricing Benchmarks

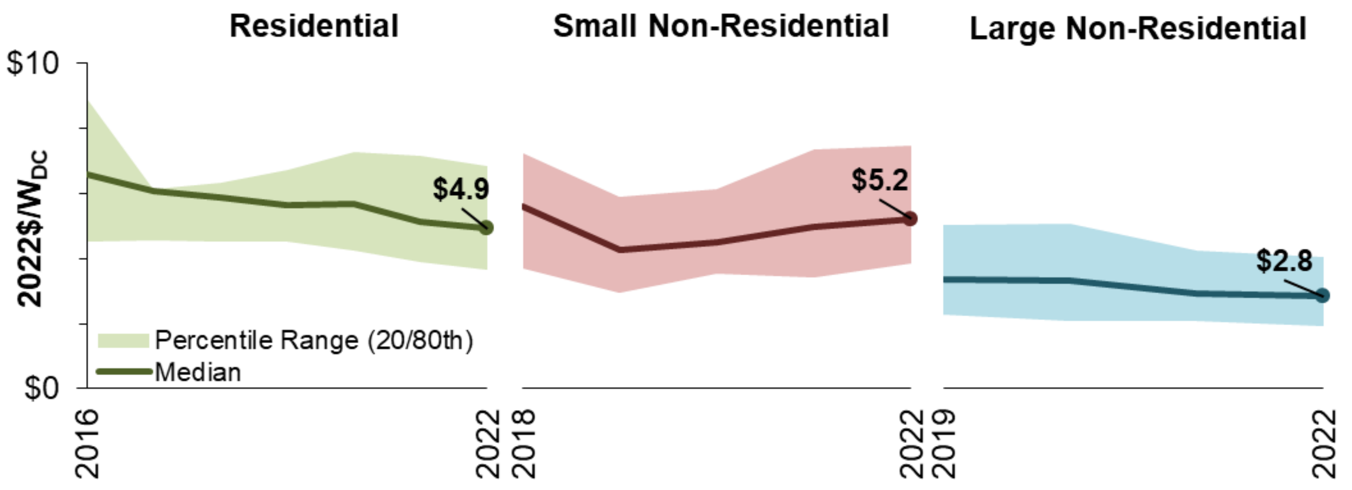


*Notes: **LBNL** data are the median and 20th and 80th percentile values among projects installed in 2022. Average costs from **SunPower and Sunrun** data are based on the companies' quarterly shareholder reports in 2022 (courtesy of J. Zuboy, NREL) and include reported installation, sales, and general & administrative costs, averaged across quarters. **EnergySage** data are the median price quotes issued in 2022, 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 2022 for a 7.9 kW residential system and a 500 kW ground-mounted commercial system (Ramasamy et al. 2022). **WoodMac** data are from the Solar Market Insight 2022 Year-in-Review, and are based on modeled turnkey prices, averaged across quarters.*

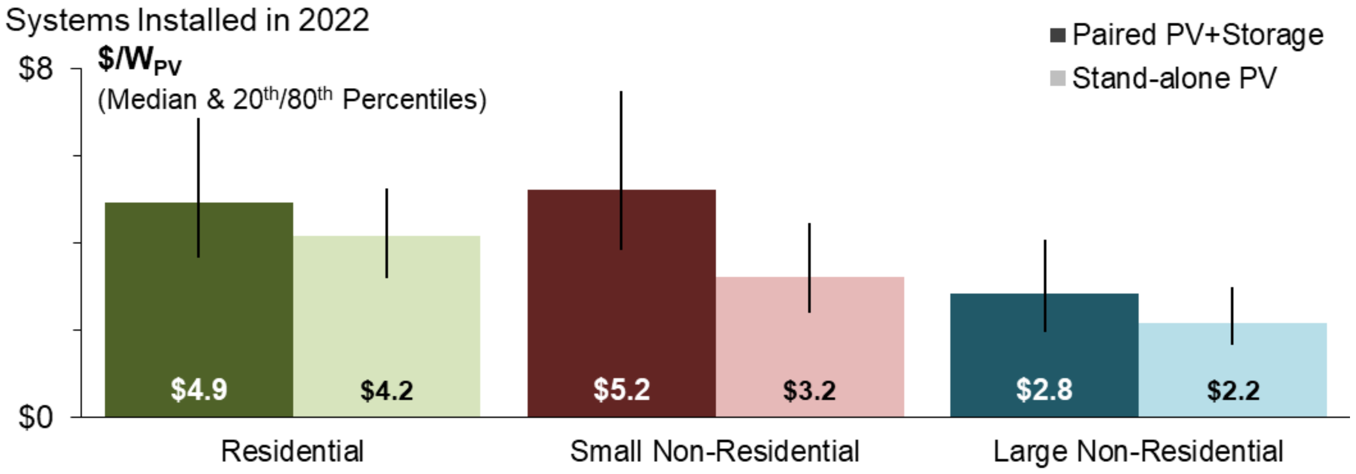
- A variety of other PV cost and pricing benchmarks exist, based on differing methods and data sources, and serving different purposes
- On the residential side, national median installed prices from Tracking the Sun (TTS) are similar to average costs reported by Sunrun, but other benchmarks align more 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 10-25% to the overall reported price

Installed Prices for Paired PV+Storage Systems

Installed Prices over Time for Paired Systems ($/kW$_{PV}$)



Installed Price Comparison: Paired vs. Stand-alone PV



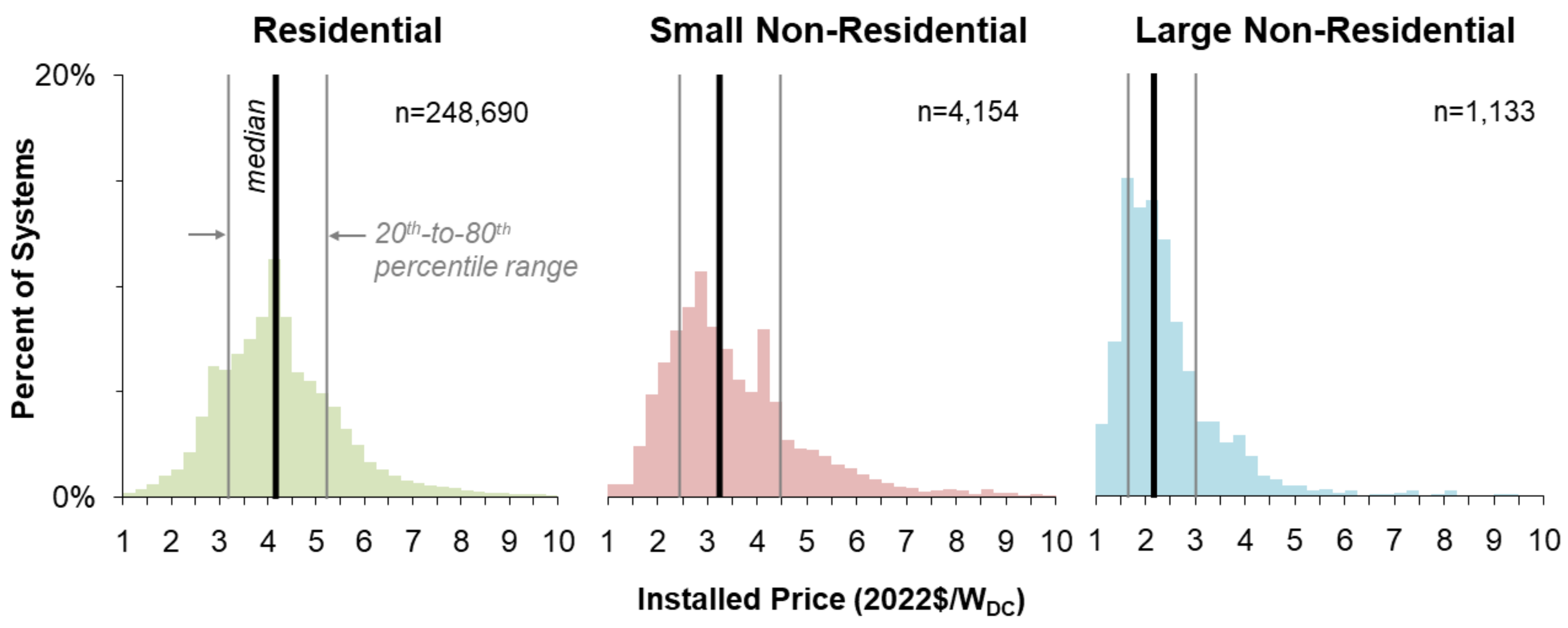
- Installed prices for paired systems presented here in terms of $ per watt of PV capacity
- Median prices for paired residential systems have been declining over time, suggestive of a maturing market
- The price decline is notable given the previously noted trend toward larger residential storage sizing over time
- Time trends for paired non-residential systems are less clear, though underlying sample sizes are small
- As to be expected, installed prices for paired systems are consistently higher than for stand-alone PV
- The multi-variate regression analysis presented later estimates a $1.5/W$_{PV}$ premium for residential PV systems with storage (significantly larger than the $0.7/W difference in median prices shown here)
- Given typical system sizing, implies a cost of about $900/kWh of storage

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.

Variability in Installed Prices

Installed-Price Variation Across Systems

Installed-Price Distribution for Stand-Alone PV Systems Installed in 2022



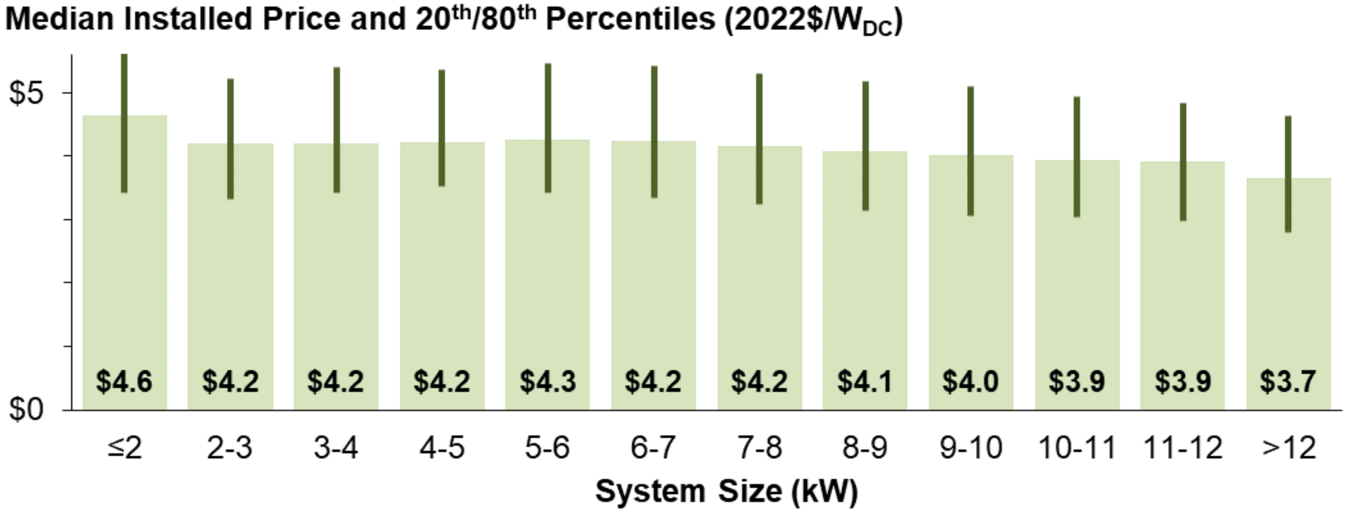
20th to 80th Percentile Bands for Systems Installed in 2022

- \$3.2/W - \$5.2/W (residential)
- \$2.4/W - \$4.5/W (small non-residential)
- \$1.7/W - \$3.0/W (large non-residential)

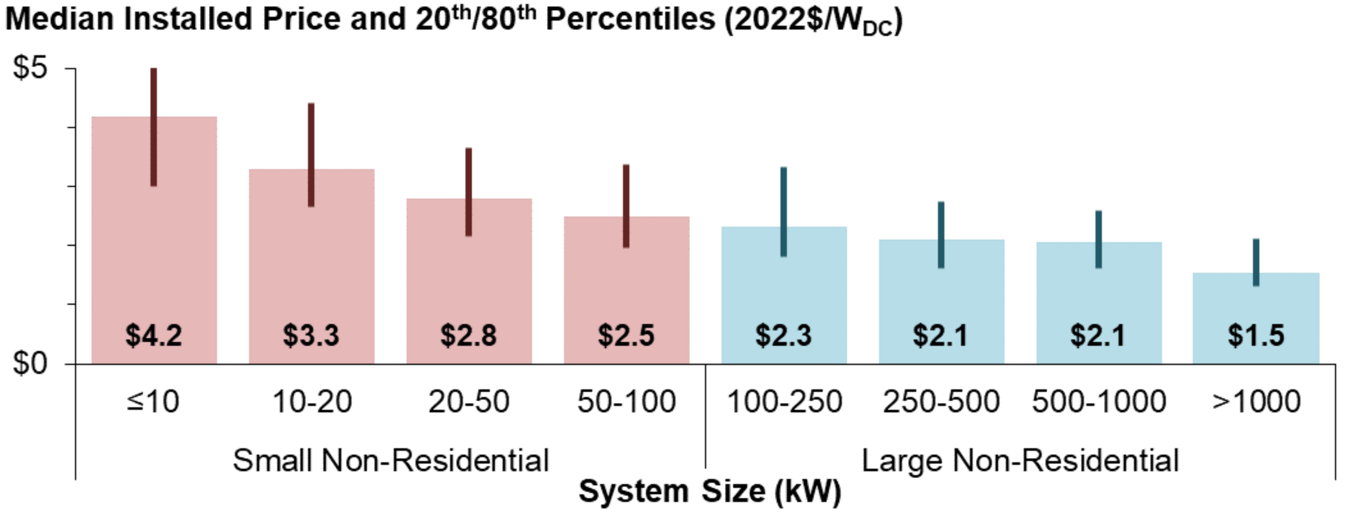
- Wide pricing variability persists within each customer segment
- Reflects underlying differences in:
  - Project characteristics
  - Installer attributes
  - Local market, policy, and regulatory environment
- We explore a subset of pricing drivers in the following slides, through a combination of ***descriptive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

Economies of Scale with PV System Size

Residential Systems Installed in 2022



Non-Residential Systems Installed in 2022



- Economies of scale arise because of the many fixed costs (e.g., permitting, customer acquisition, financing, etc.)
- Among residential systems installed in 2022, median prices were roughly $1.0/W lower for the largest residential systems compared to the smallest
- This price differential coincides with what the later regression model implies across the same size range
- Among non-residential systems, which span an even wider size range, median prices were $2.6/W lower for systems >1,000 kW, compared to the smallest non-residential systems ≤10 kW

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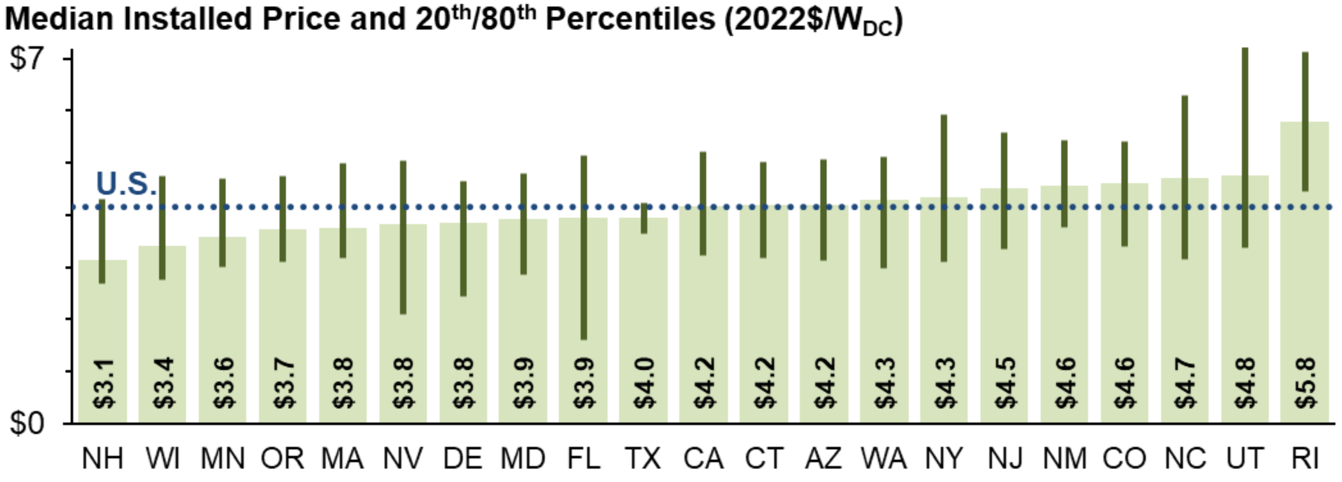
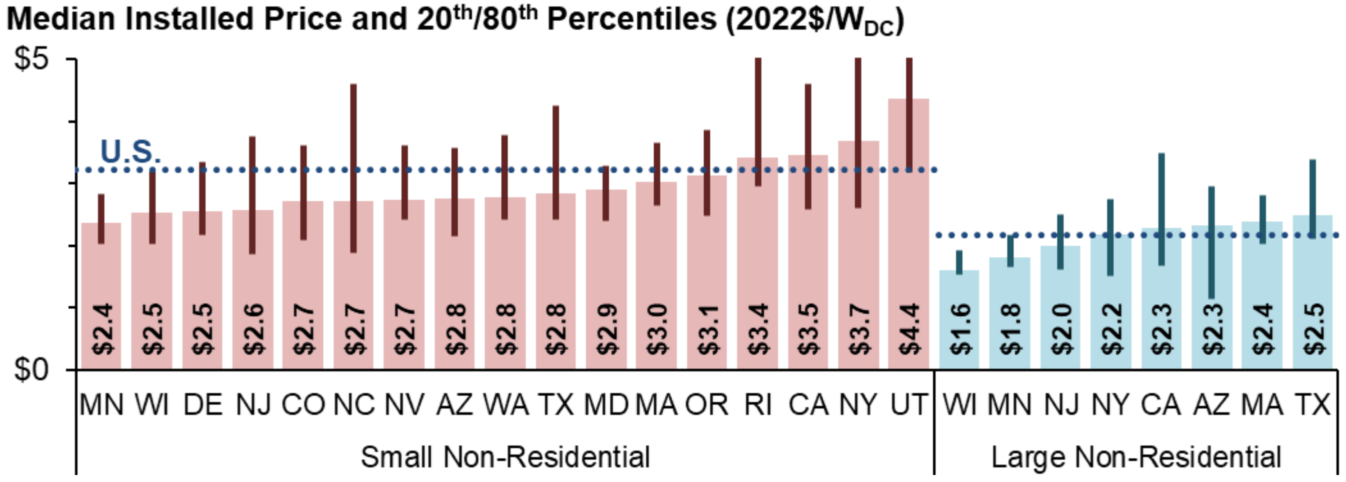
State-Level Differences in Installed Prices

Residential Systems Installed in 2022



Non-Residential Systems Installed in 2022



- Median prices vary across states within each customer segment, particularly for residential and small non-residential, where median prices vary by $2/W or more across states
- Residential pricing in CA, which dominates the sample, is near the middle of the pack
- 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 later regression analysis controls for some of those differences (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.

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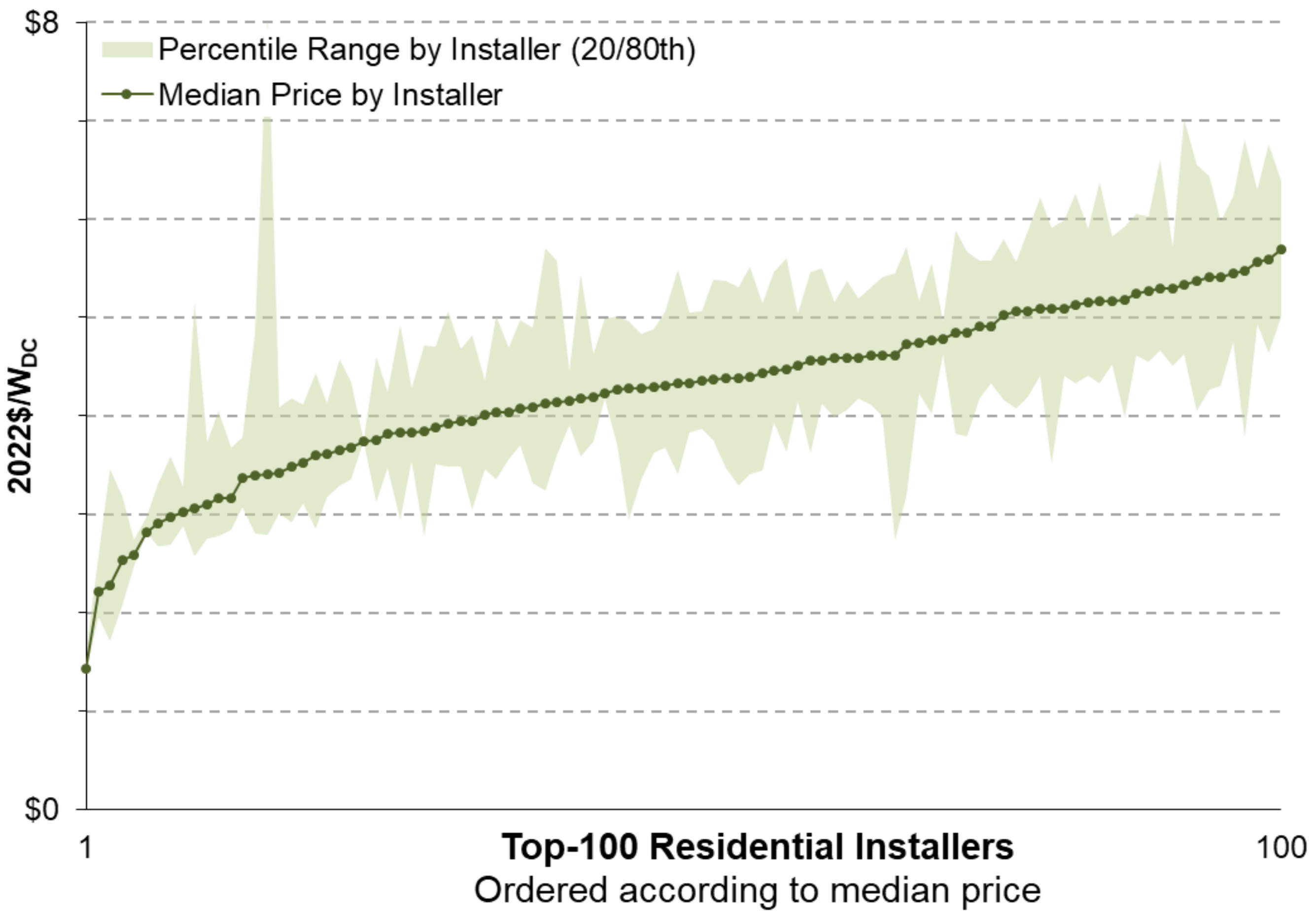
Installer-Level Pricing Differences

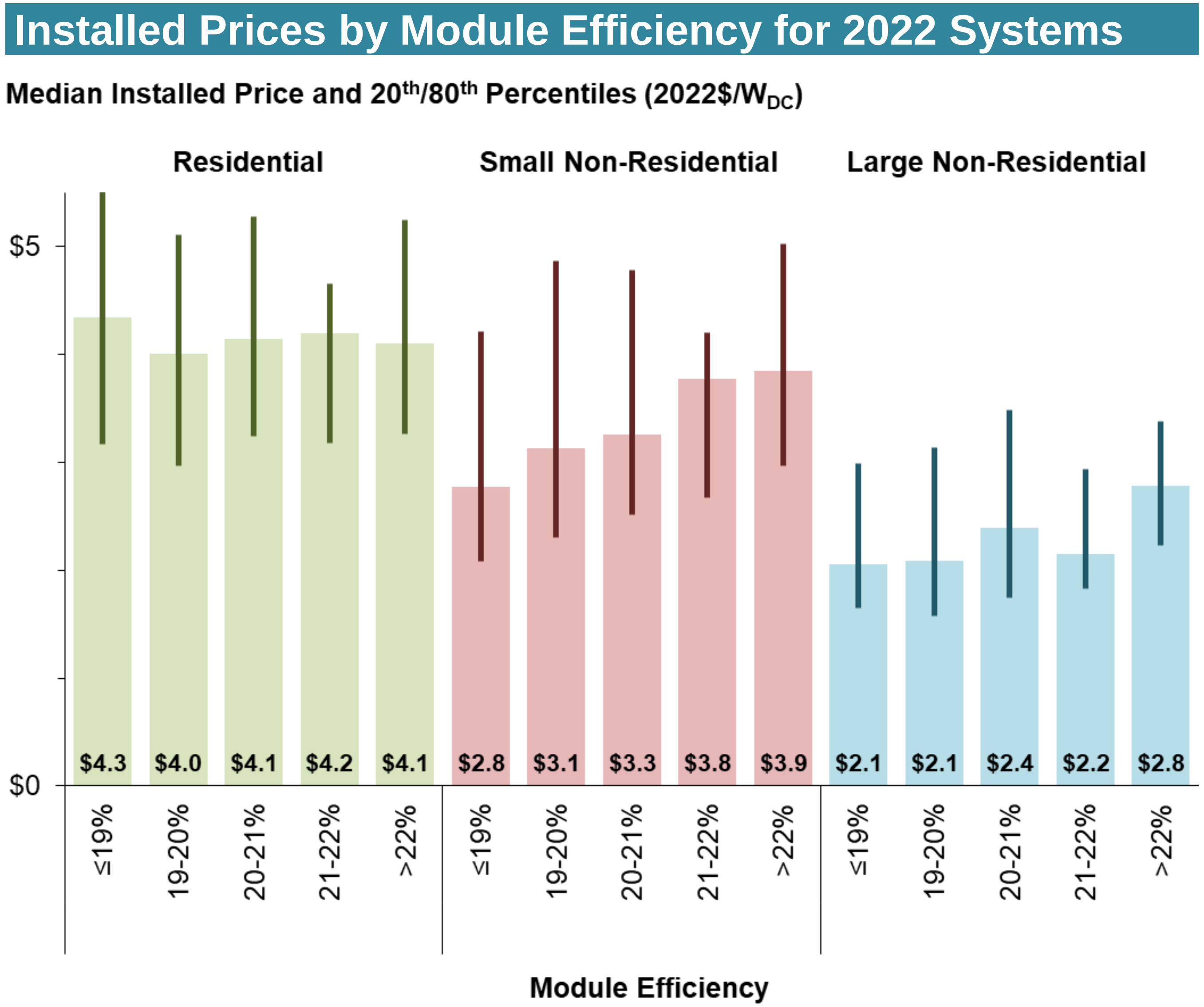
Top-100 Host-Owned Residential Installers in 2022



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 2022 ranged from $2.2/W to $5.7/W
- Various firm-level characteristics may contribute to these differences (e.g., equipment preferences and relationships, business models, loan partners), as well differences in how each installer reports prices
- Firm-level experience is one potential contributor, though the later regression analysis suggests a rather small effect (~$0.1/W range in prices between firms at the 20^{th} and 80^{th} percentile levels of experience)
- Apparent firm-level pricing differences also reflect features of the local markets in which they operate; i.e., some installers may simply tend to operate in lower or higher priced markets

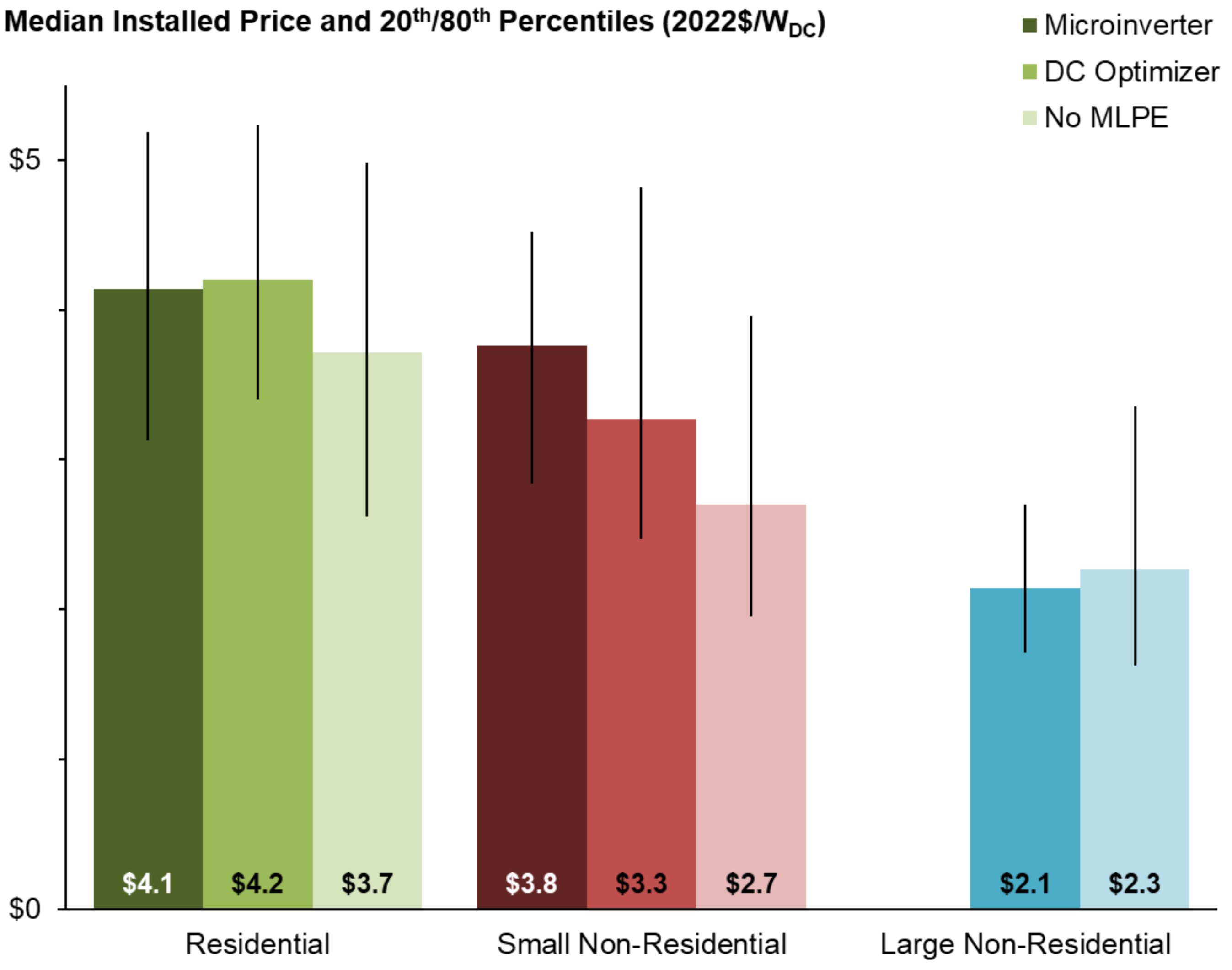
Installed-Price Differences by Module Efficiency



- Higher efficiency modules can sell at a premium, but may allow for savings on BoS costs, potentially offsetting the higher module price
- For residential systems, no obvious trend is apparent when comparing medians, though the later regression result finds that systems with "premium efficiency" (>22%) modules are roughly $0.1/W higher priced
- Descriptive results presented here do show noticeably higher prices for non-residential systems with premium-efficiency modules, potentially as a result of lower offsetting BoS cost savings

Installed-Price Differences by Inverter Technology

Installed Prices for 2022 Systems with and without MLPEs

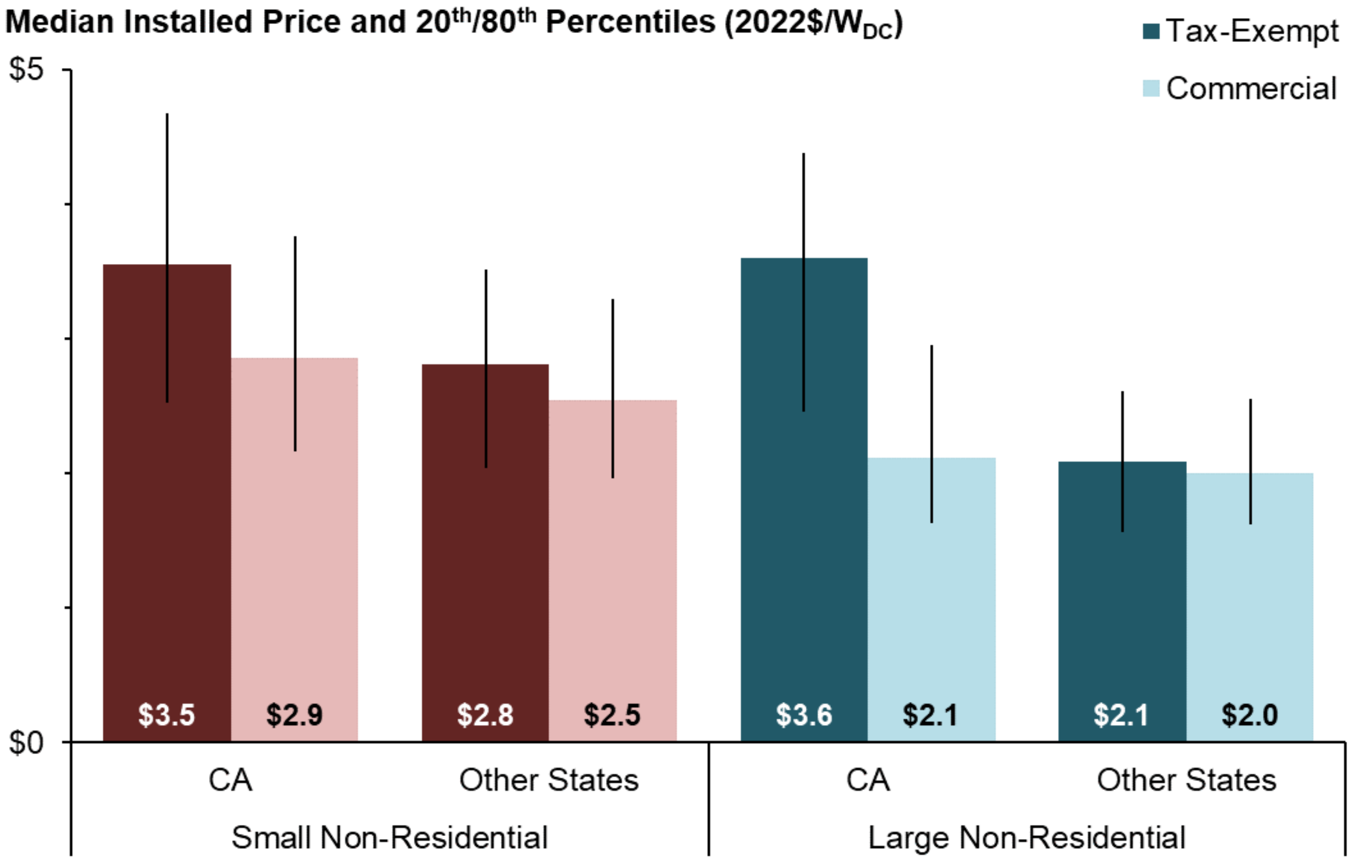


- Installed prices are generally higher for systems with some form of MLPE
- Within the residential segment, median prices are roughly equivalent for systems with microinverters and those with DC optimizers (in both cases about $0.4/W higher than for systems without any MLPE)
- In contrast, the regression analysis shows a smaller premium of $0.2/W for systems with microinverters
- This also contrasts with the results for small non-residential systems, which show significantly higher median prices for systems with microinverters (likely the result of other factors)

Notes: No results are shown for large non-residential systems with microinverters due to insufficient sample size.

Installed-Price Differences by Non-Residential Customer Type

Tax-Exempt vs. Commercial Non-Res. Systems in 2022



Notes: Summary statistics are based on a somewhat narrow subset of data providers who provide customer segmentation details for non-residential systems.

- In California, installed prices are higher for tax-exempt site hosts (schools, government, non-profits), compared to prices for commercial site hosts
- Differences are especially pronounced among large non-residential systems
- Differences between commercial and tax-exempt customers are considerably smaller in other states
- In general, higher prices for systems at tax-exempt customer sites could reflect a number of possible characteristics of tax-exempt customers, for example:
  - 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 used to explain variation in ***residential*** installed prices in 2022

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

- Dependent variable (*p*) is installed price (in $/W); independent variables include system, market, and installer-level factors, as well as state (*S*) and quarterly (*Q*) fixed-effects; many of the system-related variables are binary
- Complements the descriptive analysis by showing the effects of individual pricing drivers while controlling for inter-dependencies among those factors
- Coefficients in the table represent the average change in PV installed price ($/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)	-0.14*
	System size squared	0.002*
	Premium module (binary)	0.09
	Microinverter (binary)	0.21*
	DC optimizer (binary)	0.43*
	New construction (binary)	-0.60*
	Ground-mounting (binary)	0.28*
	Battery storage (binary)	1.47*
Market	Market size (x1,000)	-0.03
	Population density (x1,000)	0.03
	Median zip-code income (x10,000)	-0.05*
Installer experience (x1,000)		-0.01
	N	230,122
	R^2	0.12

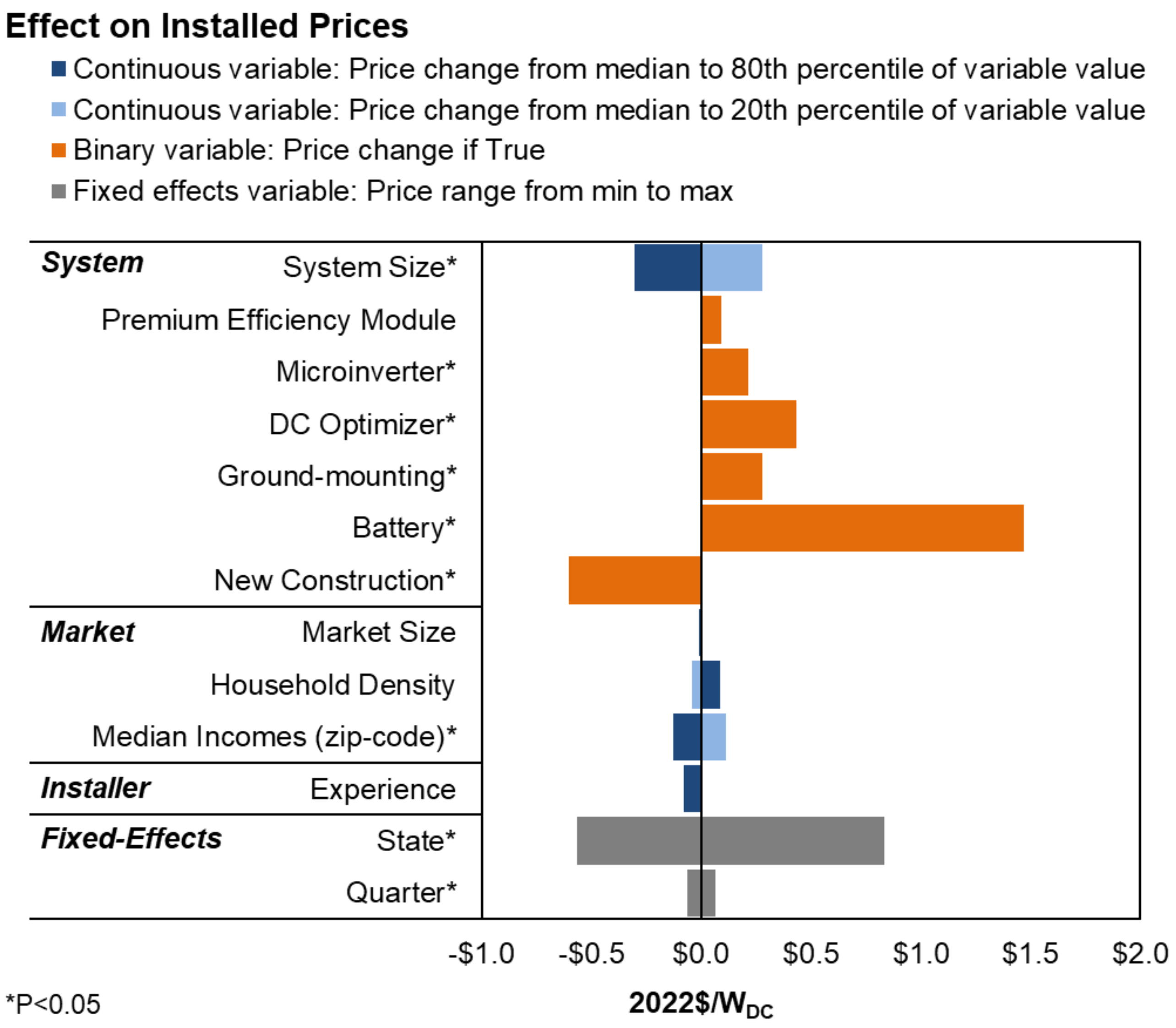
* p<0.05

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

- 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)

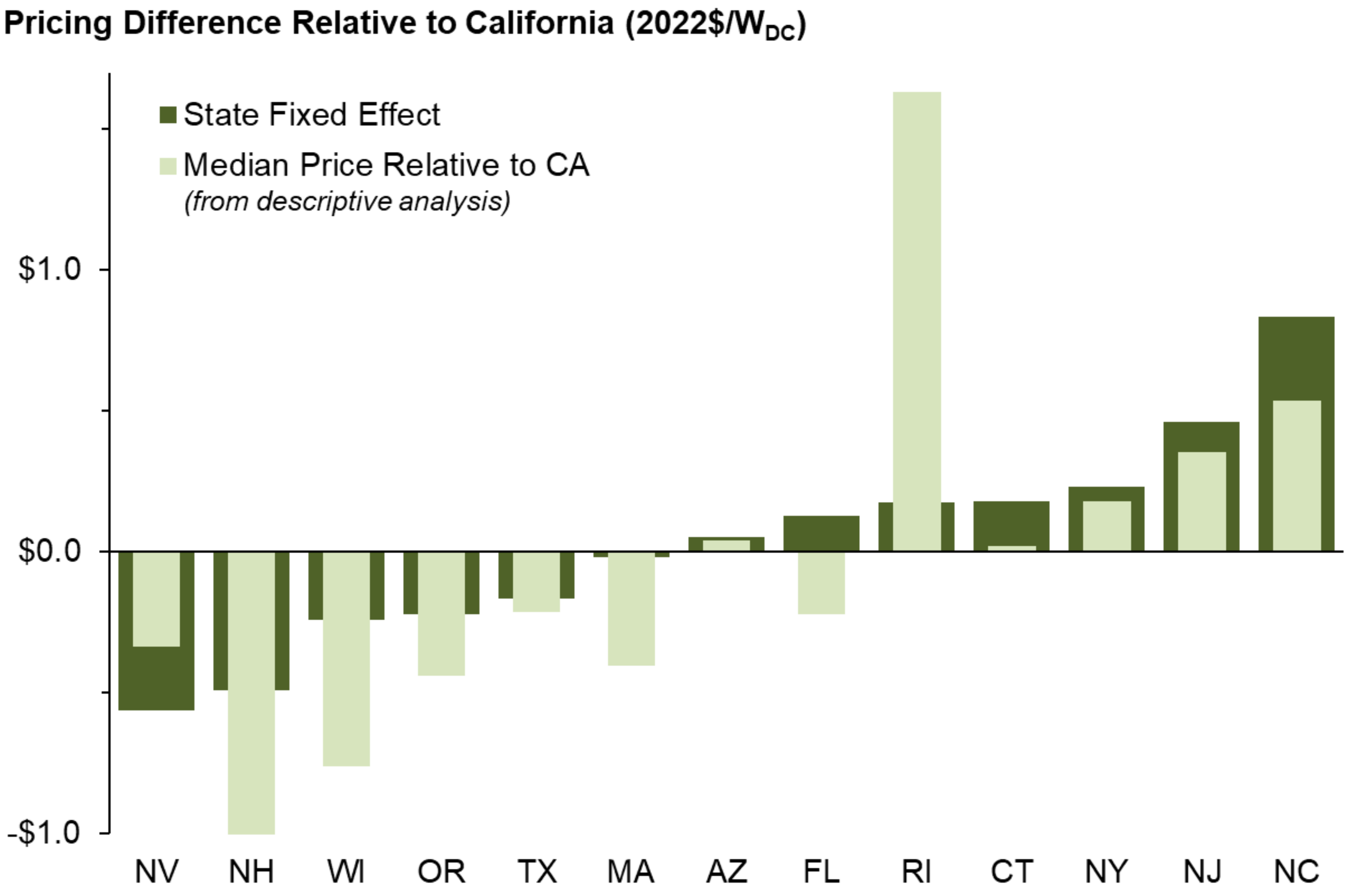


Notes: *For continuous variables, the figure shows the effect on system prices associated with moving from the median to the 20th percentile and from the median to the 80th percentile values of each variable. For binary variables, the figure shows the effect if that binary variable is true, and for fixed 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
- Fixed effects may be larger or smaller than the simple difference in state median prices, and may even point in different directions
- RI is a dramatic case, where the fixed effects are far smaller than the difference in medians, though this is largely due to a sampling issue (regression is based on a smaller sub-sample with all the requisite variables)
- Across most of the states shown, fixed effects vary within a band of roughly ±$0.3/W, which reflects additional unexplained differences across states (e.g., due to unobserved variables and/or idiosyncrasies of the data)

Additional Insights from Residential Regression Results

- **New Construction:** The model suggests that prices are $0.6/W lower for systems installed during new home construction, consistent with previous research.[a]
- **Ground-Mounting:** Though relatively uncommon in the residential sector, the model indicates that ground-mounting adds about $0.3/W to the installed price.
- **Battery:** The coefficient for battery reflects the added costs of installing ~5 kW of battery storage (10-14 kWh, depending on the manufacturer). Regression coefficient implies that a storage system of this size adds around $2,100 per kW of battery power capacity or around $900 per kWh of energy storage capacity.
- **Market size:** The negative coefficient on market size suggests that prices are generally lower in markets with more cumulative PV installations.
- **Population Density:** The positive coefficient on population density suggests that prices are generally higher in more densely-populated areas (e.g., in cities rather than rural areas).
- **Median Zip-Code Income:** The coefficient on median income is negative, suggesting that prices are lower in higher-income areas; previous studies have found different results.[b]

Additional Resources
For further reading on analyses of PV prices related to these findings, see: a) “Solar Economies of Scope through the Intersection of Four Industries.” 2018. NREL. b) “Deconstructing Solar Photovoltaic Pricing.” 2016. The Energy Journal.

For more information

Download the report, data, and other related materials:
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Contact the corresponding authors:

Galen Barbose (GLBarbose@lbl.gov, 510-495-2593)
Naïm Darghouth (NDarghouth@lbl.gov, 510-486-4570)

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Appendix

List of Entities Contributing Data

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 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 National Grid*
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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