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Tracking the Sun: Pricing and Design Trends for Distributed Photovoltaic Systems in the United States, 2021 Edition

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Tracking the Sun

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

2021 Edition

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September 2021

trackingthesun.lbl.gov

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Overview

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

- **Focuses on projects installed through 2020**
- **Describes trends related to:**
  - **Project characteristics**, including system size and design, ownership, customer segmentation, and other attributes
  - **Median installed price trends**, both long-term and recent trends, focusing on host-owned, stand-alone PV systems
  - **Variability in pricing** according to system size, state, installer, module efficiency, inverter technology, and non-residential customer type
- **Multi-variate regression further isolates the impact of individual pricing drivers**

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

Data Sources, Methods, and Market Coverage

Data Sources

Tracking the Sun relies on project-level data

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

63 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 2020 come from 26 states

Data sources have evolved over time, as incentive programs have phased out

- In many cases, utilities and agencies have opted to continue data collection through other channels

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 2020 dollars
- Direct current (DC) Watts (W), unless otherwise noted

Installed Price: Up-front $/W price paid by the PV system owner, prior to incentives

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

* 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 may not be strictly comparable to those reported for host-owned systems.

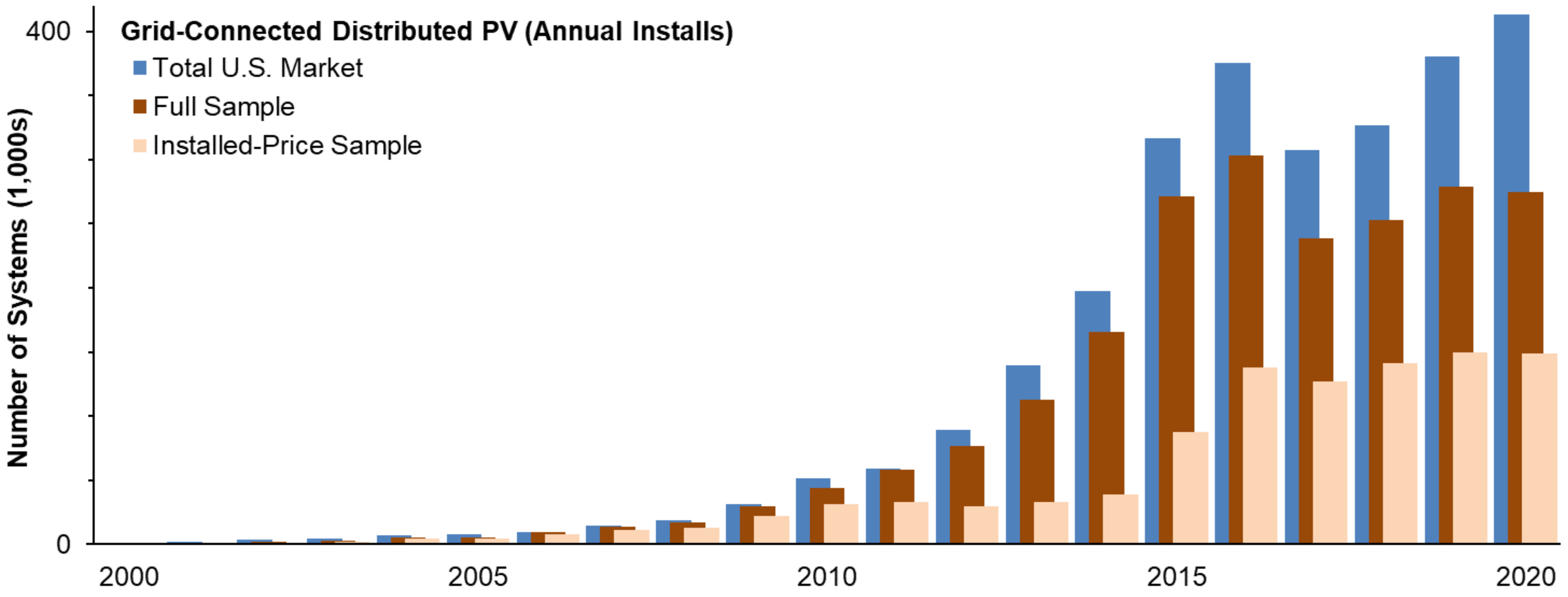
Sample Size Relative to Total U.S. Market

Full Sample

- **2.2 million** systems through 2020 (79% of U.S. market)
- 280,000 systems installed in 2020 (67% of U.S. market)

Installed-Price Sample

- **1.0 million** systems through 2020
- 150,000 systems installed in 2020



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

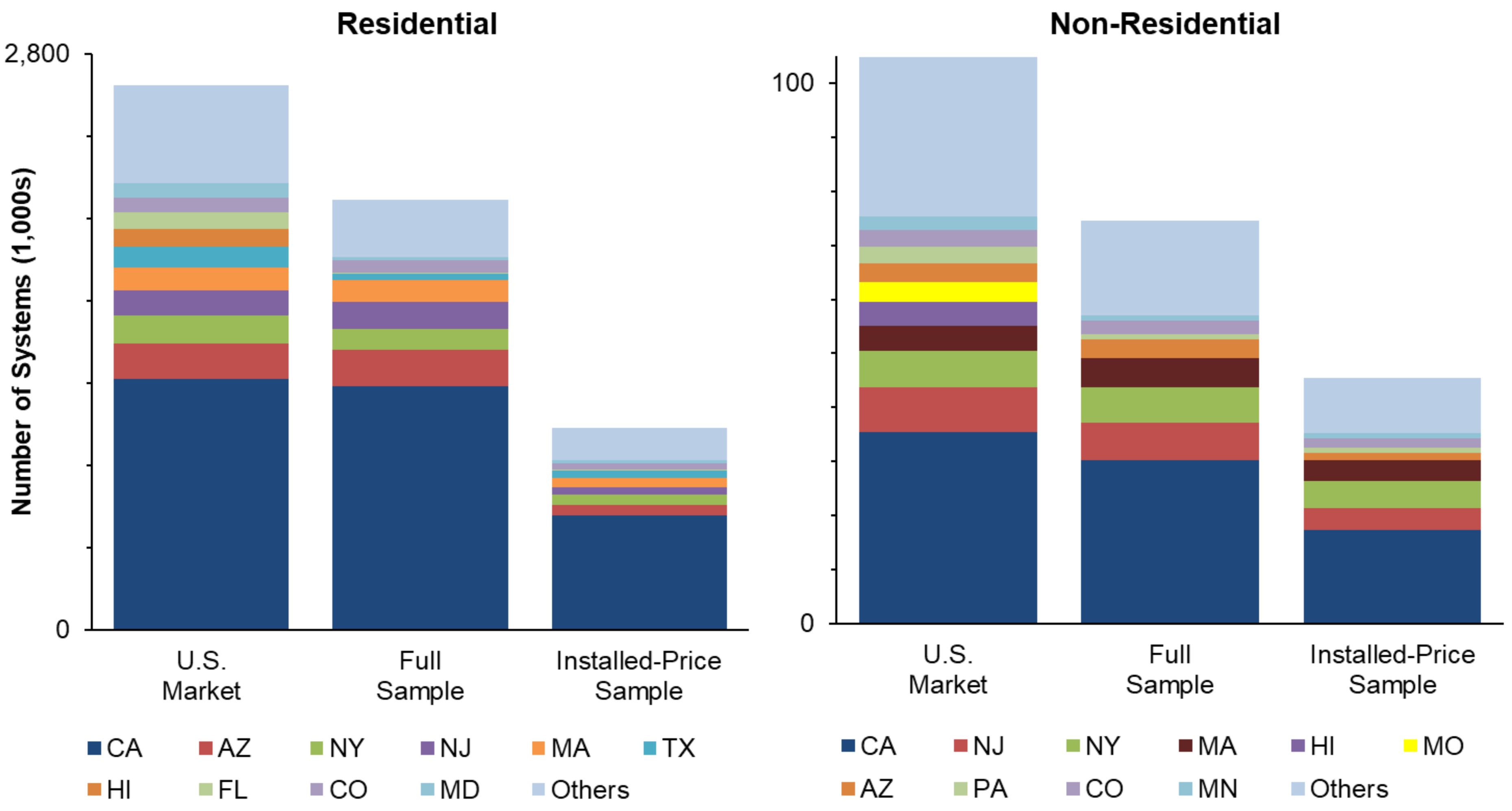
Gap between Installed-Price Sample and Full Sample: Primarily TPO systems and systems missing installed price data; several states included in the full sample provided no installed price data

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

State-Level Sample Distribution and Market Coverage

- Similar overall level of market coverage for both residential and non-residential
- CA dominates the sample, as in the larger U.S. market, but is over-represented in the sample
- In general, coverage among the larger state markets is fairly strong, with some notable gaps for TX and FL
- Smaller state markets (aggregated in the figures as “Others”) are under-represented in the sample

Cumulative Installs through 2020 (thousands)



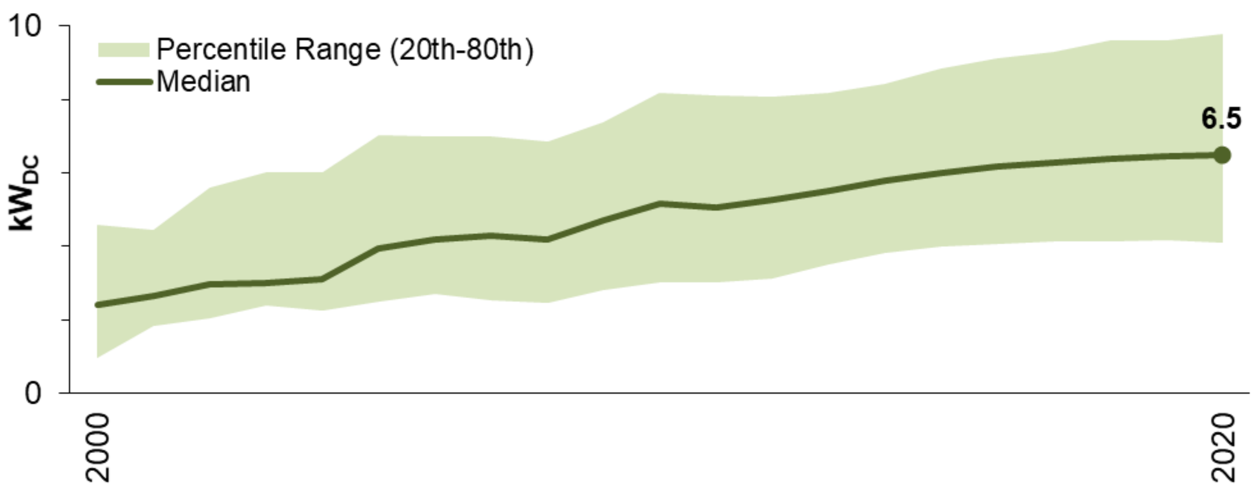
Notes: Data for the total U.S. market are from Wood Mackenzie and SEIA (2021). The figures show the top-10 states in each customer segment, based on cumulative U.S. installations through 2020, and all other states are combined in the “Other” category.

Distributed PV System Characteristics

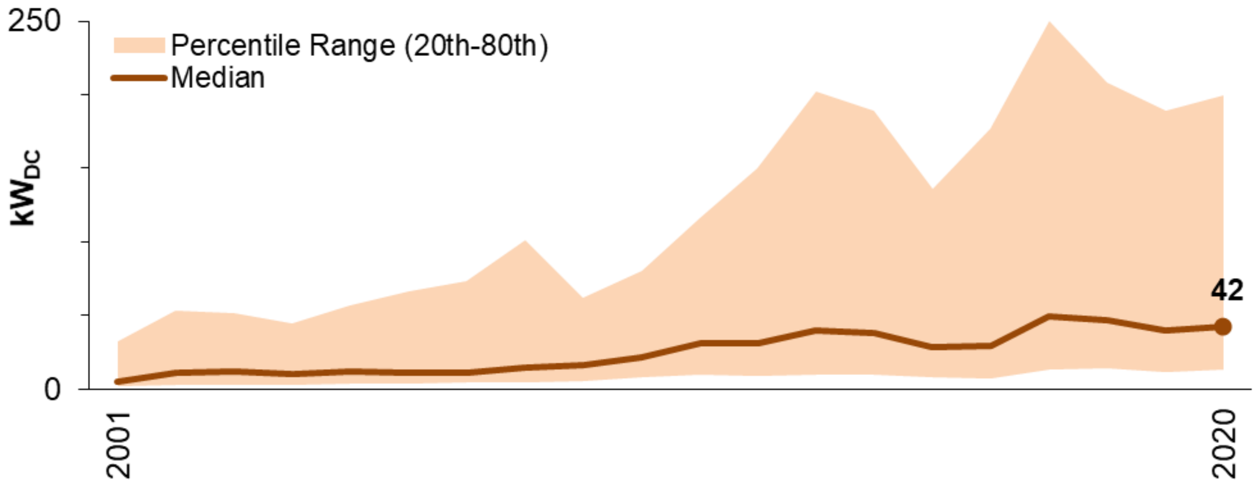
Based on Full Sample

System Size Trends

Residential System Size Time Trends



Non-Residential System Size Trends

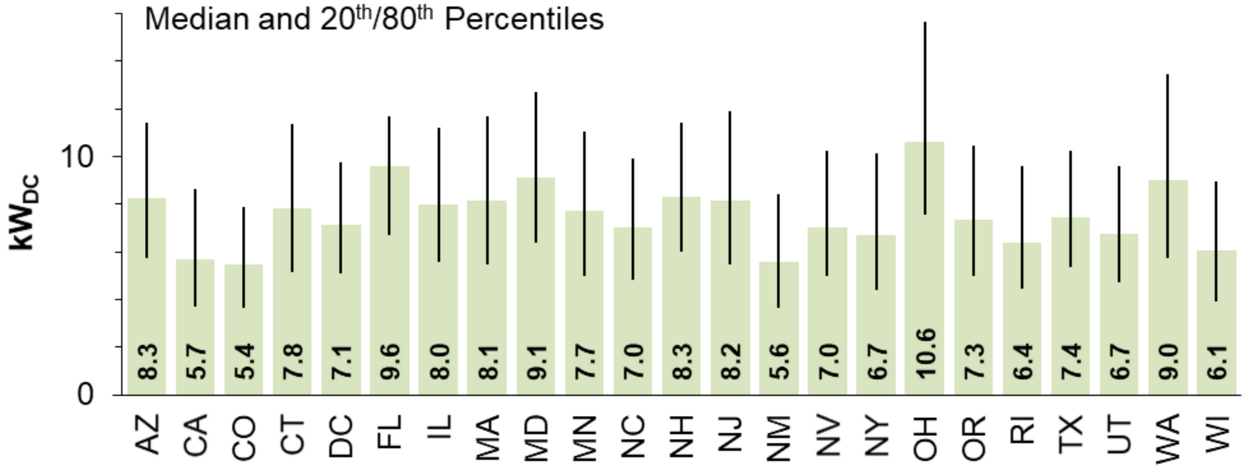


- Residential system sizes have been rising over time, from a median of 2.4 kW in 2000 to 6.5 kW in 2020, driven by declining module costs and rising module efficiencies (esp. for space-constrained projects)
- Residential system sizes can vary widely (e.g., from roughly 4-10 kW between the 20-80th percentiles in 2020), reflecting differences in customer consumption levels, available roof space, net metering rules, etc.
- Non-residential sizes have generally been rising over time as well, especially at the upper end of the size range as large projects have become more common
- While the median non-residential systems size was just 42 kW in 2020, the distribution has a long upper tail, with 20% of systems in 2020 larger than 200 kW

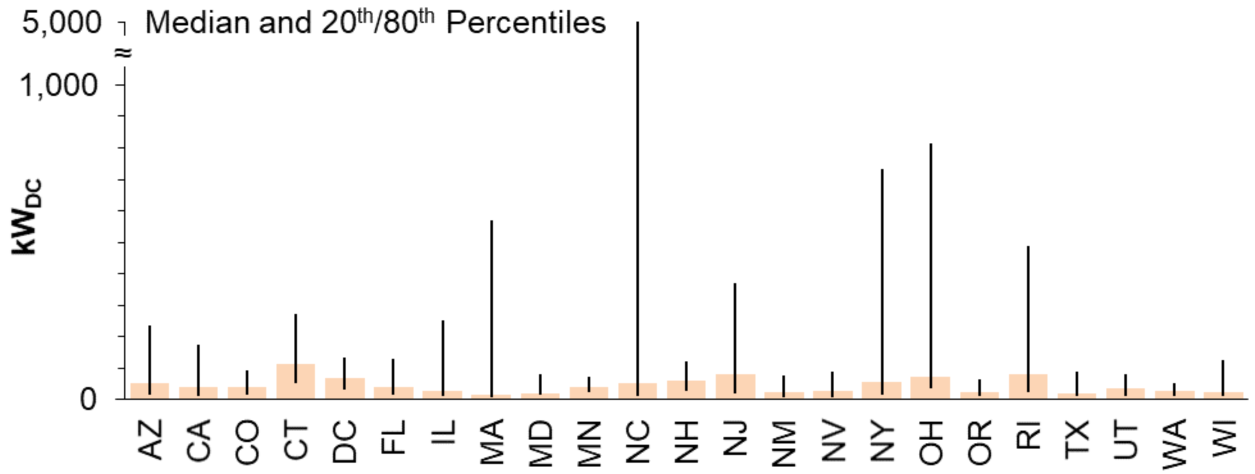
Notes: Summary statistics for any given year are shown only if at least 20 observations are available.

System Size Comparisons by State

Residential System Sizes by State (2020)



Non-Residential System Sizes by State (2020)

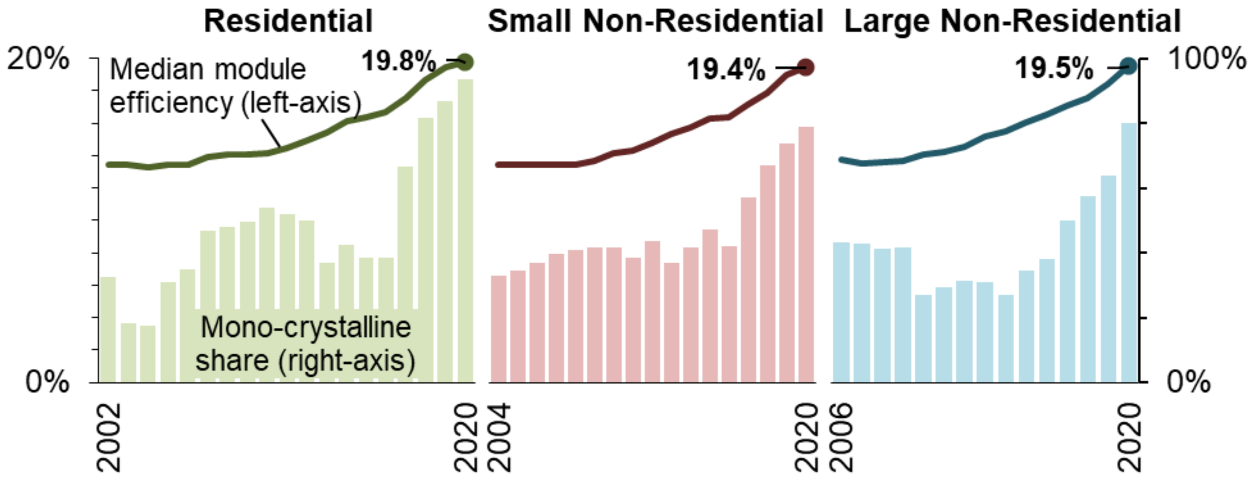


- Residential system sizes vary significantly across states, from a median of 5.4 kW (CO) to 10.6 kW (OH) for systems installed in 2020
  - CA, by virtue of its large share of the sample and relatively small system sizes, pulls the aggregate US median down; most states have median sizes of at least 7.5 kW
  - Broad spread in system sizing prevalent across states
- State-level differences in non-residential system sizing are most notable at the upper end of the distributions
  - Five states (MA, NC, NY, OH, RI) had 80th percentile sizes greater than ~500 kW in 2020, indicating a relatively significant share of large systems
  - Most other states had 80th percentiles <100 kW
  - Note that these findings may be sensitive to the completeness of the non-res. sample in each state

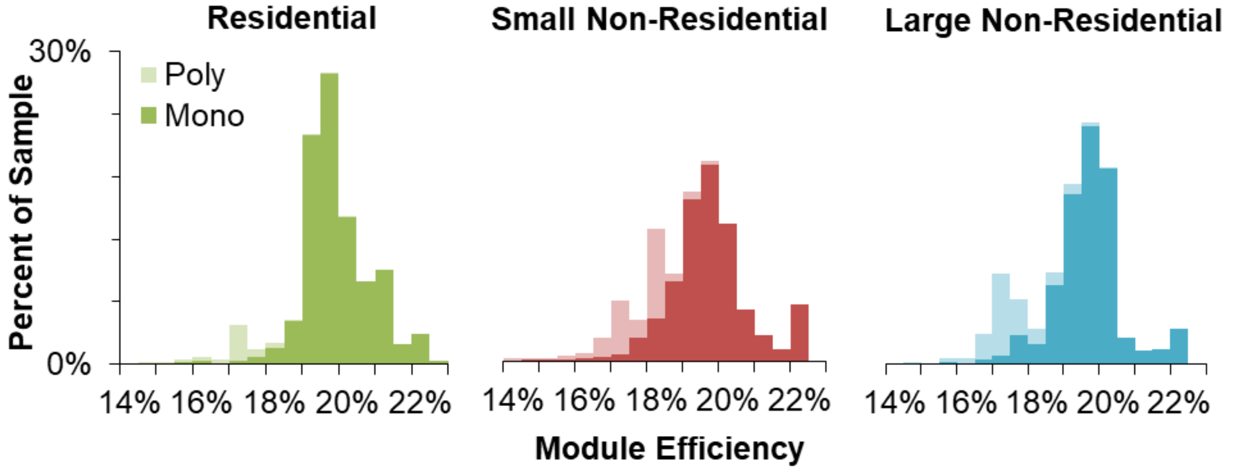
Notes: Summary statistics for any given state are shown only if at least 20 observations are available.

Module Efficiency Trends

Module Efficiency Time Trends



Module Efficiency Distribution (2020)

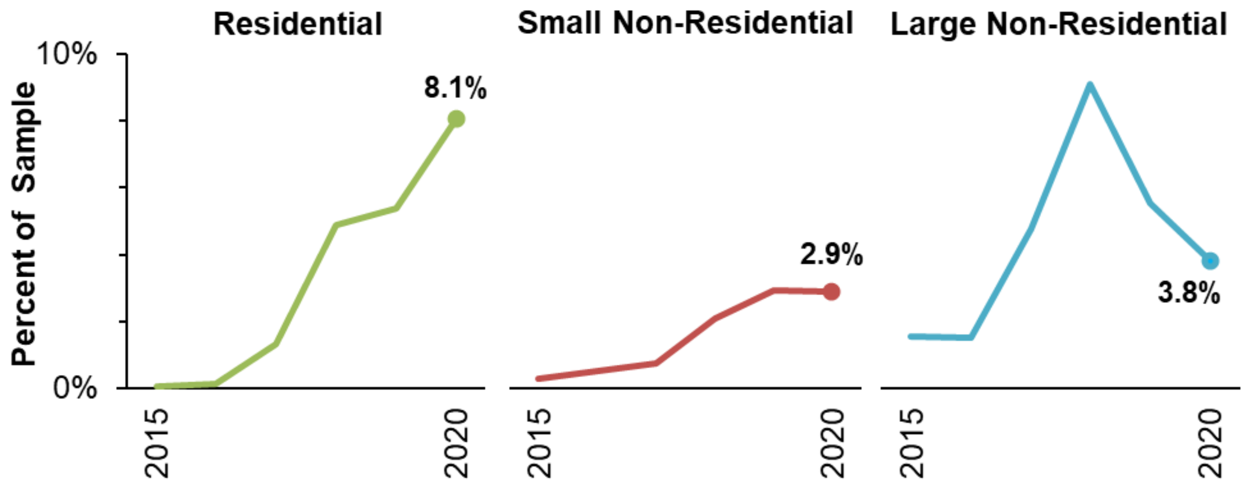


- Module efficiencies have risen steadily over time: for example, among residential systems, median module efficiencies rose from 13.4% in 2002 to 19.8% in 2020, with similar rises for non-residential systems as well
- Rise in recent years partly reflects rapid increase in market share of mono-crystalline modules (79-94% share in 2020, depending on the segment), as well as other factors—e.g., increasing use of passivated emitter rear-cell (PERC) technology
- That said, a diversity of module technologies and efficiency levels are still in use, with efficiencies ranging anywhere from 16-22% among systems installed in 2020, with poly-silicon modules at the lower end and premium-efficiency mono modules at the upper end

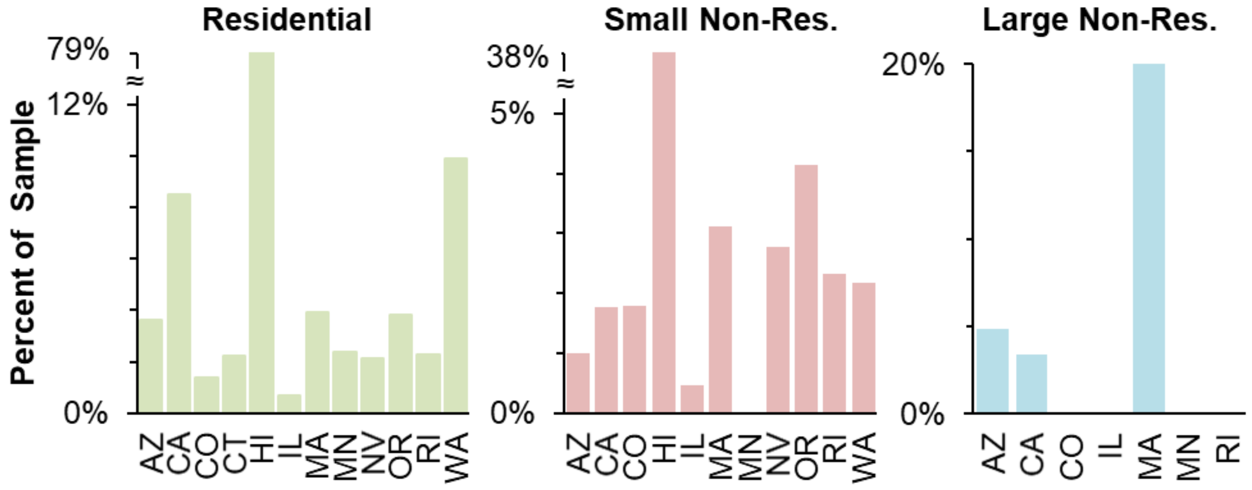
Storage Attachment Rates

Percent of PV systems installed each year that include storage

Storage Attachment Rates over Time



Storage Attachment Rates by State (2020)

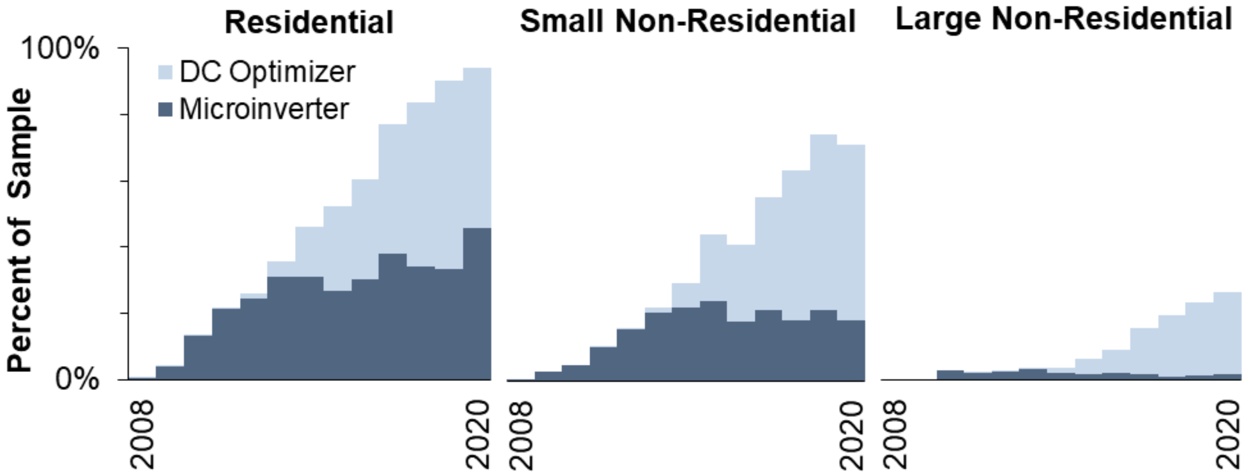


- Residential attachment rates have risen over time, reaching 8.1% of the sample in 2020 (overstating the U.S. market average—see notes)
- Non-residential attachment rates are lower, and trends for large systems reflect fluctuations in the CA market
- HI has, by far, the highest storage attachment rates of any state, driven partly by net metering reforms that incentivize self-consumption
- CA is home to the vast majority of paired systems, driven by storage rebates and resilience concerns
- Attachments rates outside of CA and HI are generally lower, though pockets of activity exist elsewhere (e.g., WA state, where the data come solely from Puget Sound Energy, and large non-res. systems in MA)

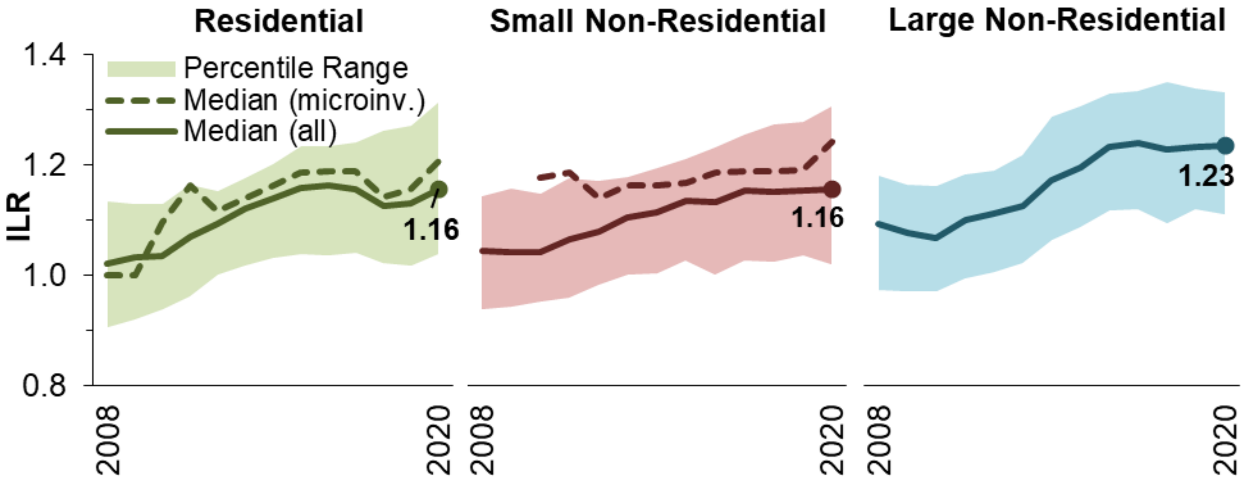
Notes: The sample includes nearly complete data from CA and HI, which represent the overwhelming majority of all U.S. residential PV+storage systems, but data from many states are either wholly missing or are incomplete; thus, the sample-average attachment rate likely overstates the U.S. market average. The bottom figure shows only those states for which storage status is available for at least 20 systems and at least 50% of all statewide systems in the sample for the particular customer segment and year shown. Note the breaks in the y-axes for Residential and Small Non-Residential systems, to accommodate the data for HI.

Inverter-Related Trends

Microinverter and DC Optimizer Trends



Inverter Loading Ratios (DC-to-AC Ratio)

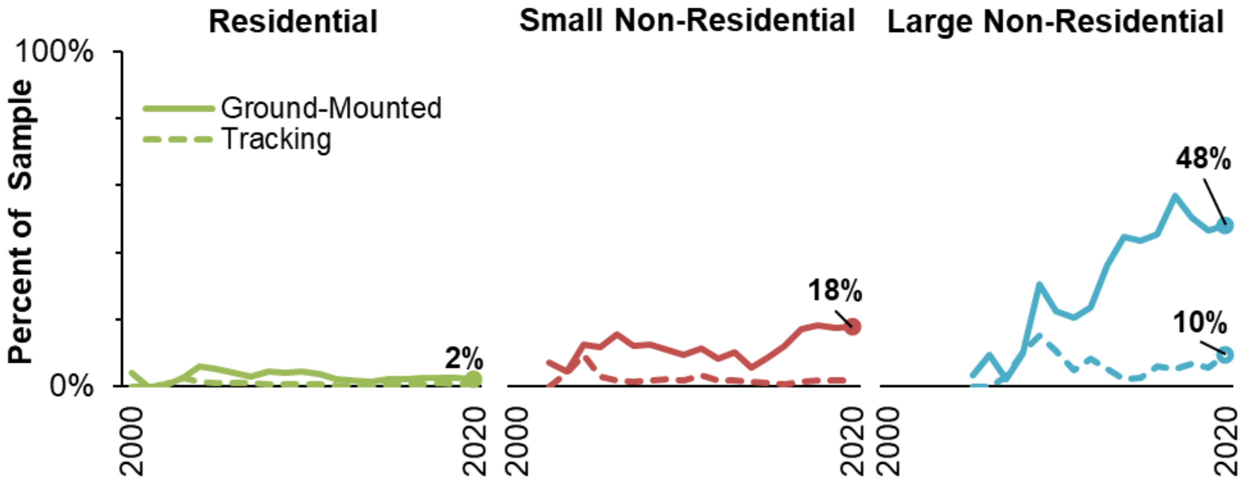


- Module-level power electronics (MLPEs), which include both microinverters and DC optimizers, have continued to gain share across the sample
- MLPEs are almost universal within the residential sector (94% of systems in 2020) and dominant for small non-residential (71%), but considerably less common for large non-residential (26%)
- DC optimizers dominate MLPE growth since 2013, though 2020 saw a notable uptick in microinverter share
- Inverter-loading ratios (the ratio of module-to-inverter nameplate ratings) have generally grown over time with declining module costs; also tend to be higher for large non-residential systems and for systems with microinverters (depending on manufacturer)

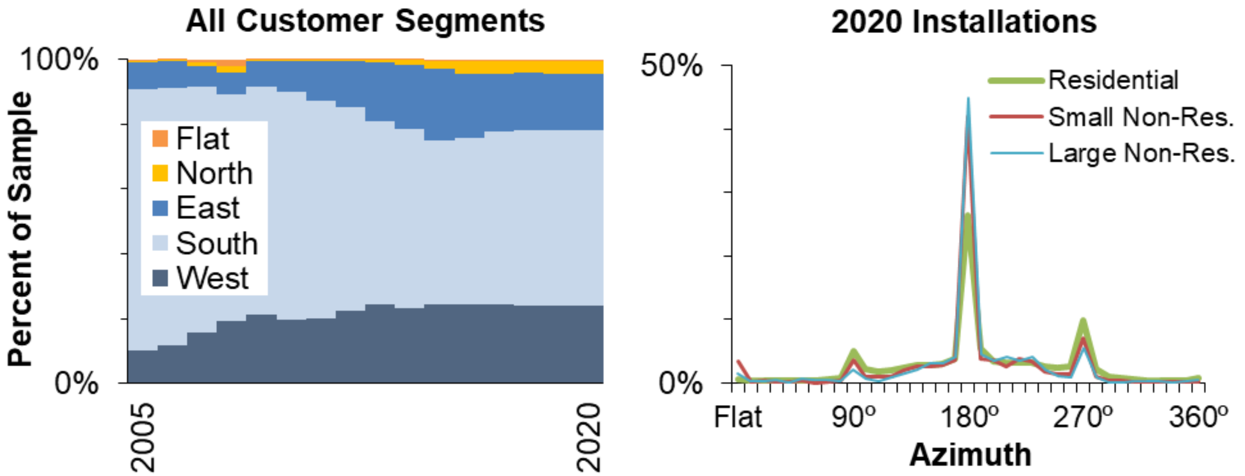
Notes: DC Optimizer share consists of only systems with SolarEdge inverters and may therefore slightly understate the actual share of power optimizers in the data sample.

Mounting Configuration and Panel Orientation

Ground-Mounting and Tracking Equipment (2020)



Panel Orientation

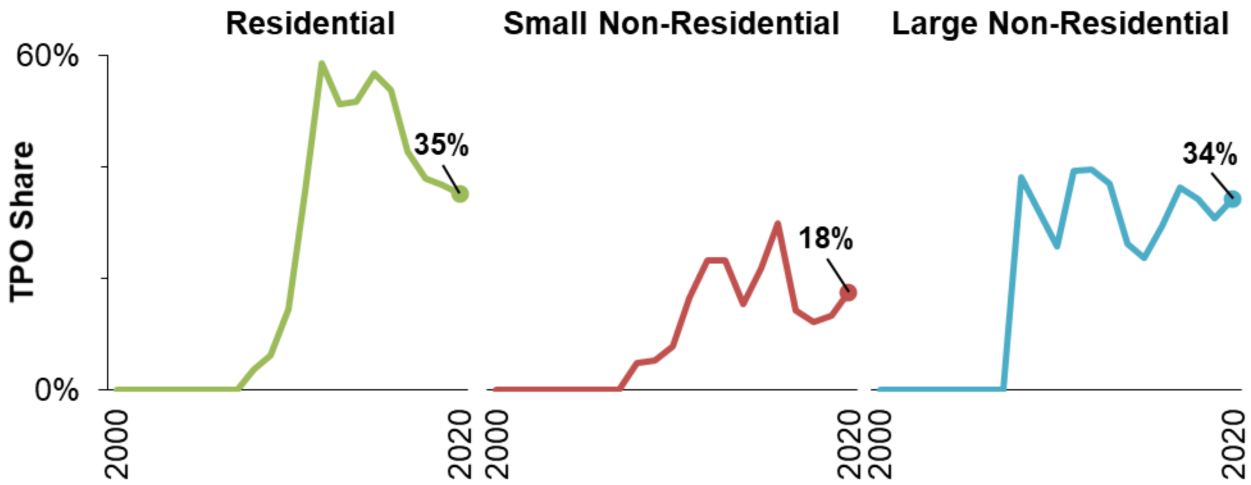


- Ground-mounting (as opposed to roof-mounting) is most prevalent among large non-residential systems, while use of tracking is limited
  - Almost half (48%) of large non-residential systems in 2020 are ground-mounted, while 10% have tracking
  - Ground-mounting much less common among residential and small non-residential systems, and negligible shares have tracking
- Panel orientations have become more diverse over time, though haven't changed much in recent years
  - 54% of systems installed in 2020 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

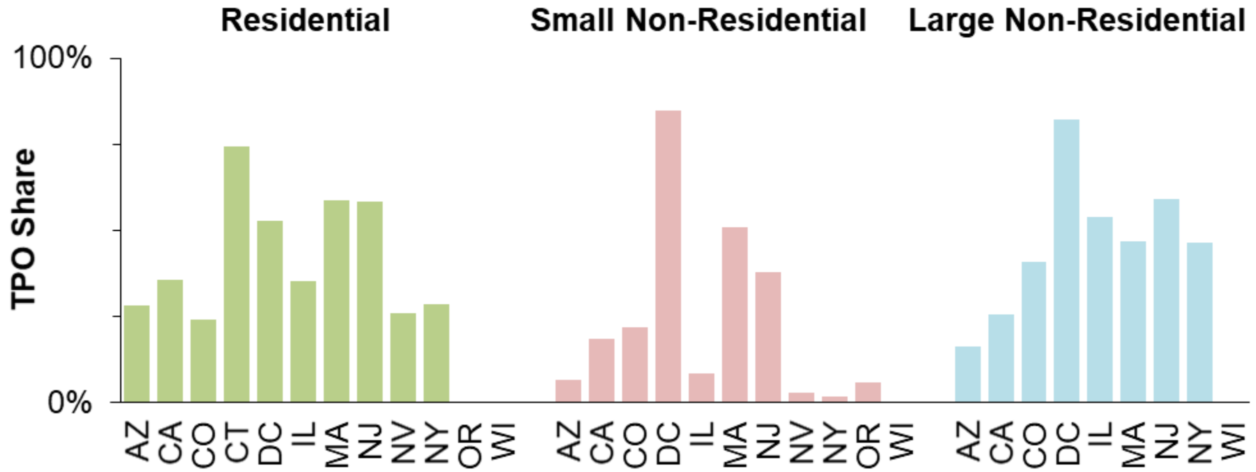
Notes: Summary statistics for any given year are shown only if at least 20 observations are available. Figures in the bottom panel exclude tracking systems, and in both figures, the orientation is based on the primary array (for systems with multiple arrays facing different directions). For the figure 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 (2020)

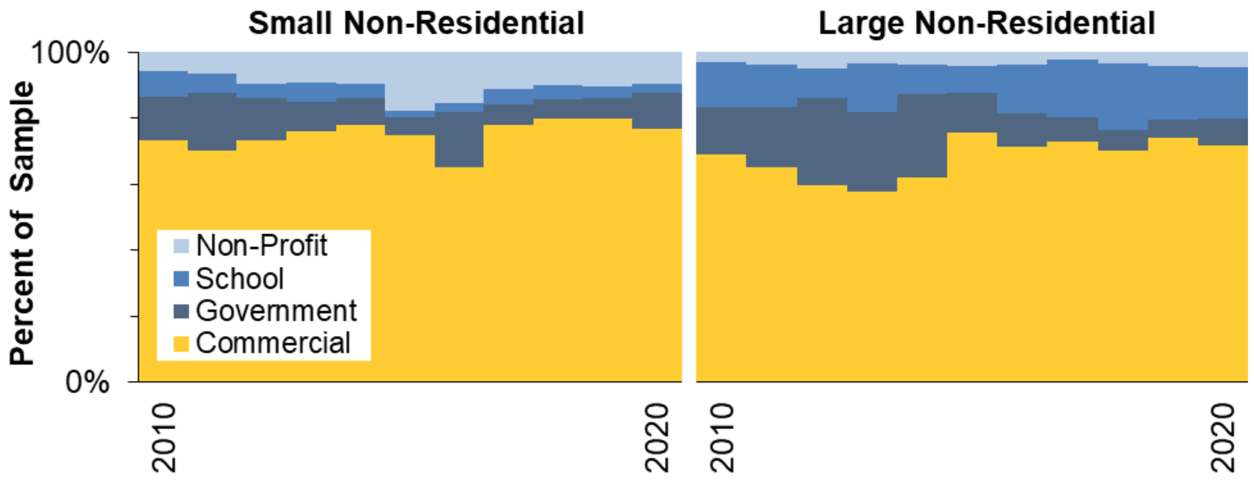


- Third-party ownership (TPO) in the residential sample has declined over time from its historical high of 59% in 2012 to 35% in 2020
  - Reflects emergence of residential loan products
- For the non-residential sample, TPO shares have remained comparatively steady and have historically been lower for small vs. large non-residential systems
- TPO shares at the state level vary substantially
  - Generally are higher among states with sizeable rebate programs (CT) or high solar renewable energy certificate prices (DC, MA, NJ)
  - Some states limit TPO or restrict eligibility for incentive programs to only host-owned systems

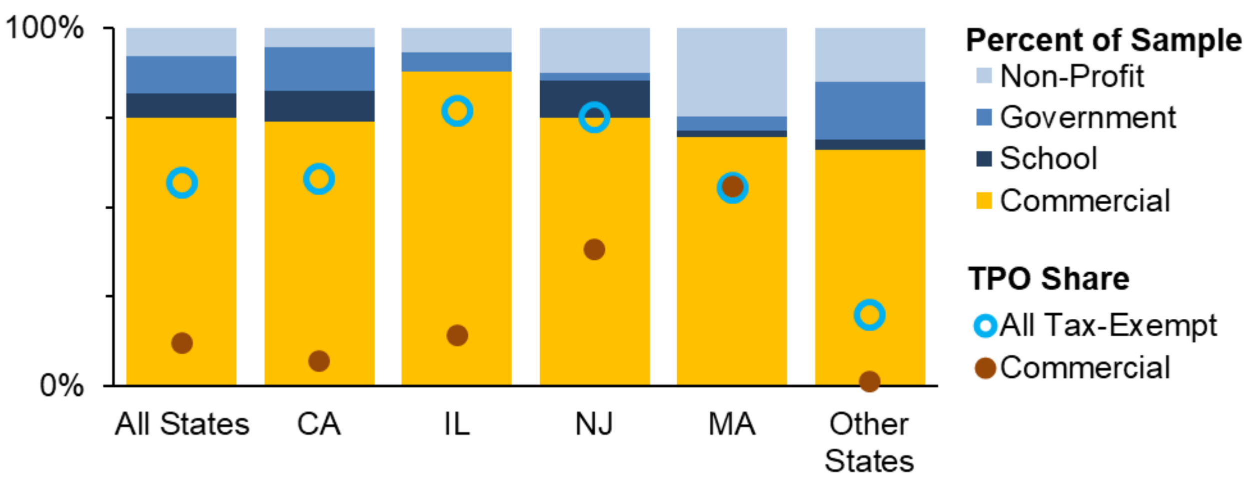
Notes: In the bottom figure, data are shown for individual states only if TPO status is available for at least 20 systems and for at least 50% of records for the given state, year, and customer segment. Furthermore, we exclude a number of states from the figure where the underlying data source may not be representative of the state as a whole, in terms of TPO shares (e.g., TX and FL, where our data come from only municipal utilities, or MD, where our data come from a statewide incentive program available only for host-owned systems).

Non-Residential Customer Segmentation

Non-Res. Customer Segmentation Trends over Time



Non-Res. Customer Segmentation by State (2020)



- For-profit commercial customers make up >70% of non-residential site hosts, with the remainder consisting of some combination of tax-exempt site hosts (schools, government, non-profits)
- Non-profits have been most prevalent among small non-residential systems, while schools and government facilities are more common within the large non-residential segment
- The overall mix of non-residential customer segments generally similar across states
- TPO considerably more prevalent among tax-exempt site hosts than for commercial hosts (57% vs. 12% in 2020), as TPO allows tax-exempt customers to monetize tax benefits

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 2020.

Median Installed Price Trends

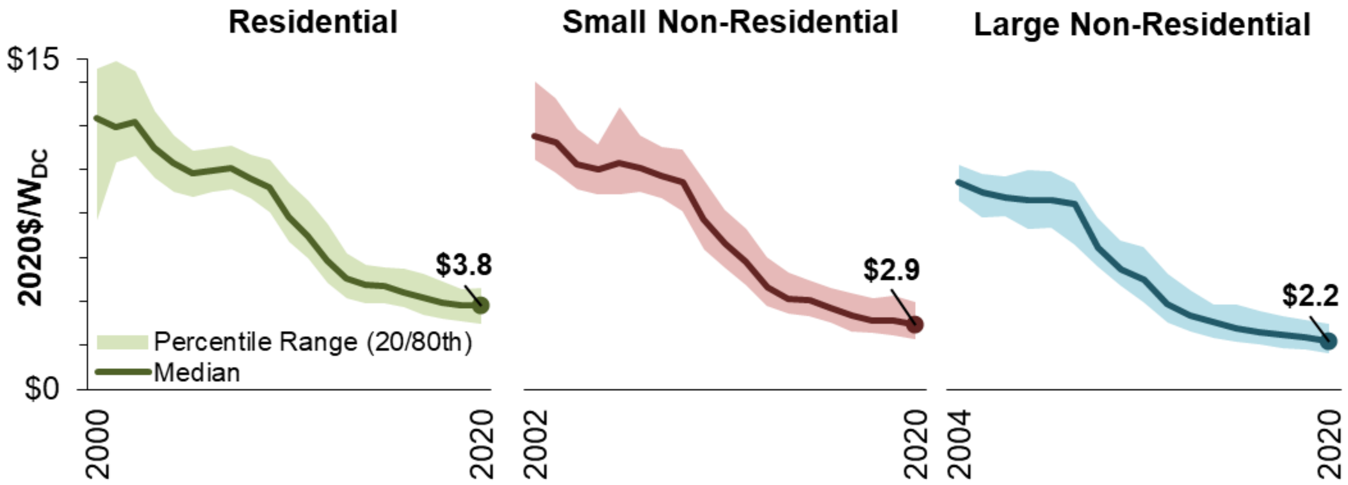
Based on Installed-Price Sample

A Few Notes on Installed-Price Data

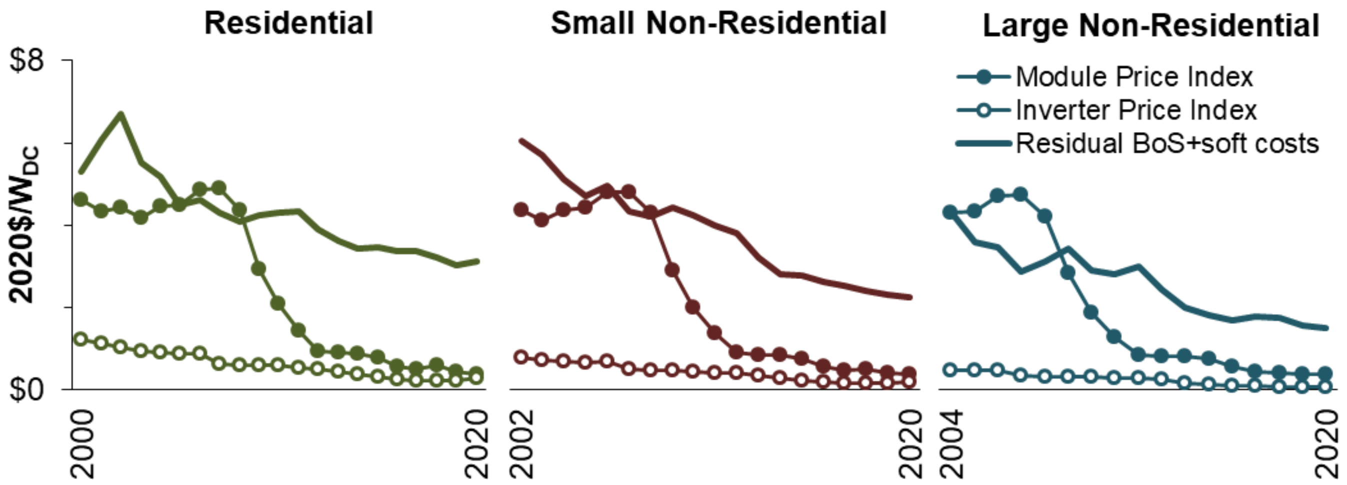
- Differs from the underlying cost borne by the developer or installer (price ≠ cost)
- Unless otherwise noted, excludes TPO, battery storage, and self-installed systems
- Historical (i.e., systems installed through 2020) and therefore may not be representative of systems installed more recently or current quotes for prospective projects
- Self-reported by PV installers or customers; susceptible to inconsistent reporting practices

National Median Prices and Component Costs over Time

National Installed Prices over Time



Underlying Trends in Component Costs

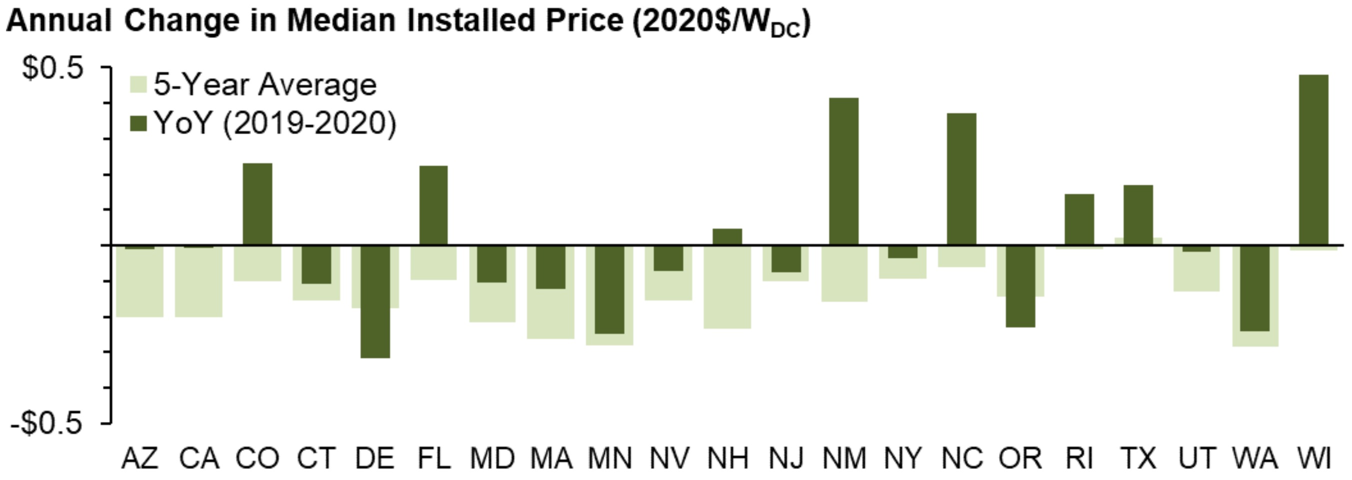


- Over the last year of the analysis period (2019-2020), median U.S. prices for residential systems remained effectively flat at $3.8/W, while falling by $0.2/W for both small and large non-residential systems
- Over the long-term, median installed prices have fallen by roughly $0.4/W per year, on average, but price declines have tapered off since 2014, after which price declines averaged $0.1-0.2/W across segments
- That tapering off is partly a function of the underlying module-cost trajectory, but also reflects growing customer acquisition costs, loan fees, and other factors embedded in the “Residual BoS+soft costs” shown in the bottom figure (note: BoS = balance of systems)
- Over the long-term, these imputed BoS+soft costs have fallen by roughly $0.1-0.2/W per year, but 2020 saw a slight uptick for residential systems

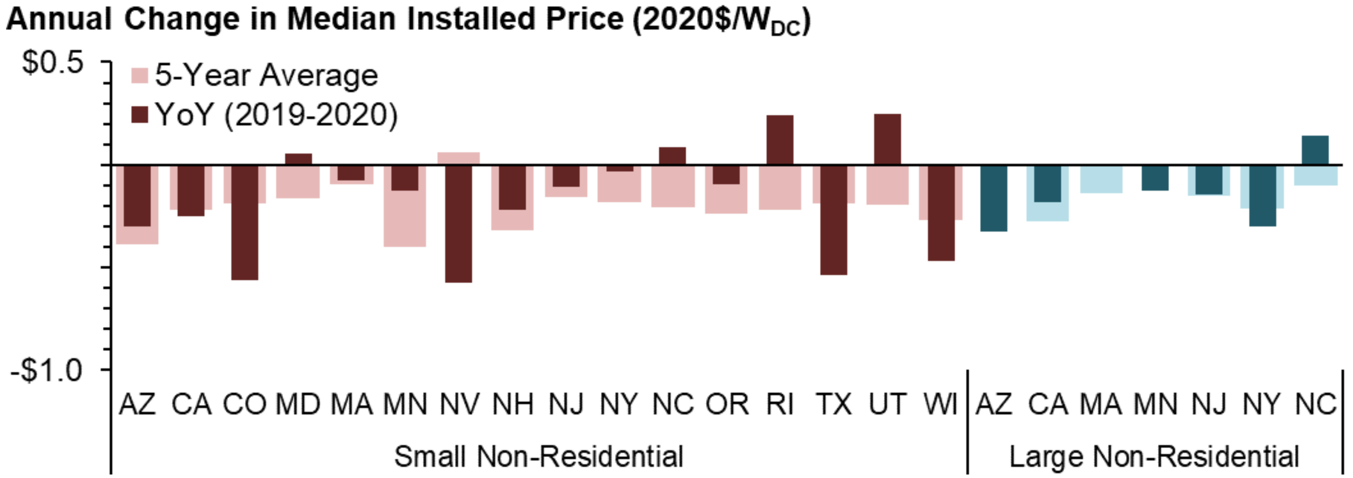
Notes: Summary statistics for any given year are shown only if at least 20 observations are available. The Module and Inverter Price Indices are based on data from SPV Market Research and Wood Mackenzie, with adjustments by Berkeley Lab in order to extend those indices back in time and to differentiate 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).

State-Level Trends in Median Installed Prices

Residential Annual Change in Median Prices



Non-Residential Annual Change in Median Prices



- Year-over-year (YoY) pricing trends at the state-level can deviate from national trends, but tend to converge over longer time frames
- National trends are driven strongly by CA, given its dominant share of the sample
- In the residential market, YoY trends range from a $0.5/W increase for WI to a $0.3/W decrease for DE
  - Over a longer 5-year timeframe, trends are more stable, with most states showing average annual declines of $0.1-0.2/W per year
- Among non-residential systems, YoY changes in median prices range from a $0.6/W decrease to a $0.2/W increase
  - Over the past 5 years, median non-residential prices have fallen by $0.1-0.3/W per year in most states

Notes: Summary statistics for any given state are shown only if at least 20 observations are available in both the start-year and end-year of the comparison period.

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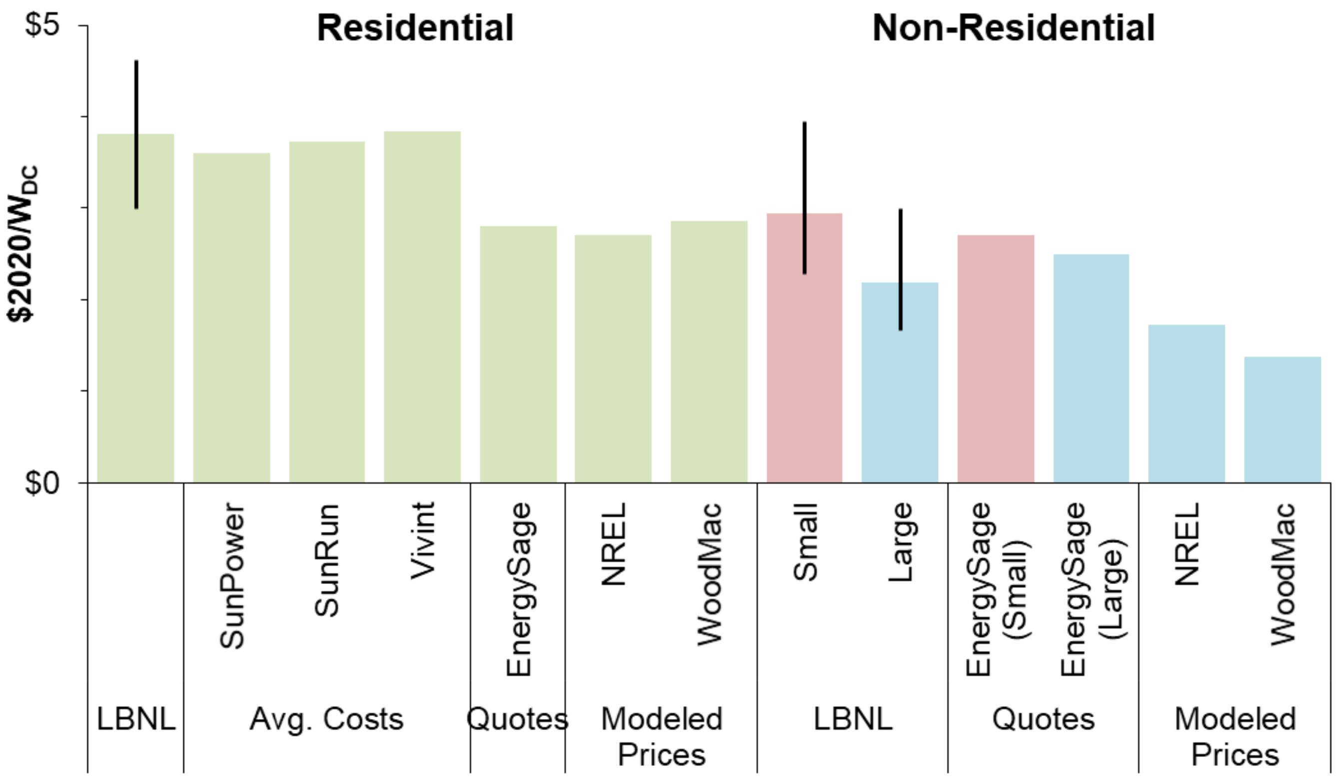
Comparison of PV Cost and Pricing Benchmarks



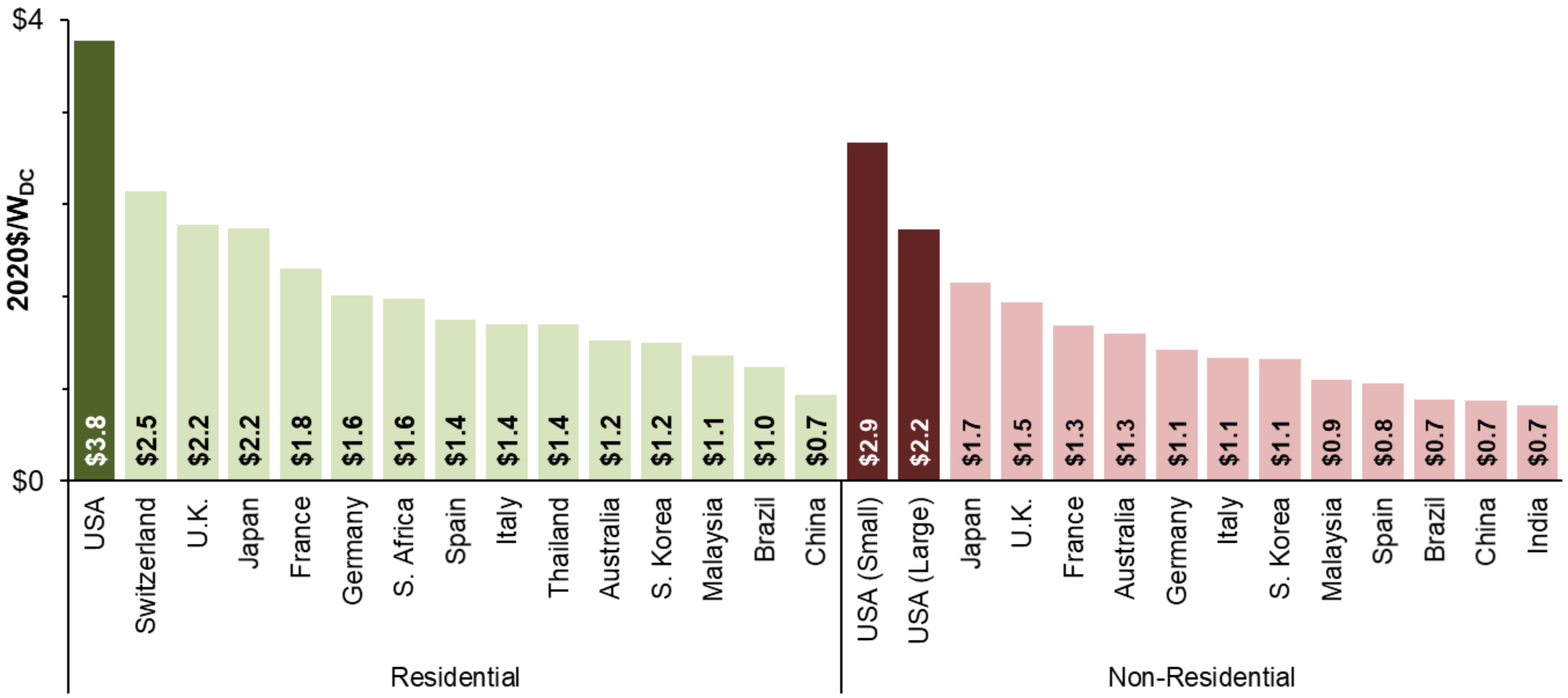
*Notes: **LBNL** data are the median and 20th and 80th percentile values among projects installed in 2020. **SunPower, SunRun** and **Vivint** data are based on the companies' quarterly shareholder reports in 2020 (courtesy of D. Feldman, NREL) and are equal to the sum of reported average installation, sales, and general & administrative costs, averaged across the four quarters. **EnergySage** data are the median price quotes issued in 2020, calculated by Berkeley Lab from data provided by EnergySage. **NREL** data represent modeled turnkey costs in Q1 2020 for a 7 kW residential system and a 200 kW commercial system (Fu et al. 2020). **WoodMac** data are from the Solar Market Insight 2020 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
- National median installed prices from *Tracking the Sun* are similar to average costs reported by SunPower, SunRun, and Vivint and are also similar to non-residential price quotes from EnergySage
- In contrast, national median prices are considerably higher than bottom-up modeled prices from NREL and WoodMac (which may be more reflective of basic “turnkey” systems) and also diverge from residential price quotes from EnergySage
- In general, divergence across benchmarks reflects differences in factors such as vintage, location, price vs. cost, scope of costs included, installer characteristics, value-based pricing, system size and design

International Comparison

- Installed prices in the United States are more than double those in most other countries, as reported by IRENA
- Comparisons may not be totally “apples-to-apples” (e.g., type and depth of underlying data, treatment of VAT); but the basic trend is no doubt real
- Installed price differences primarily due to soft costs (as differences in hardware costs are much smaller than the installed price gaps shown here)
- Lower soft costs in other countries reflect differences in, for example: solar industry business models, permitting and interconnection processes, and labor rates, among other factors

Comparison of Installed Prices in 2020 across Countries

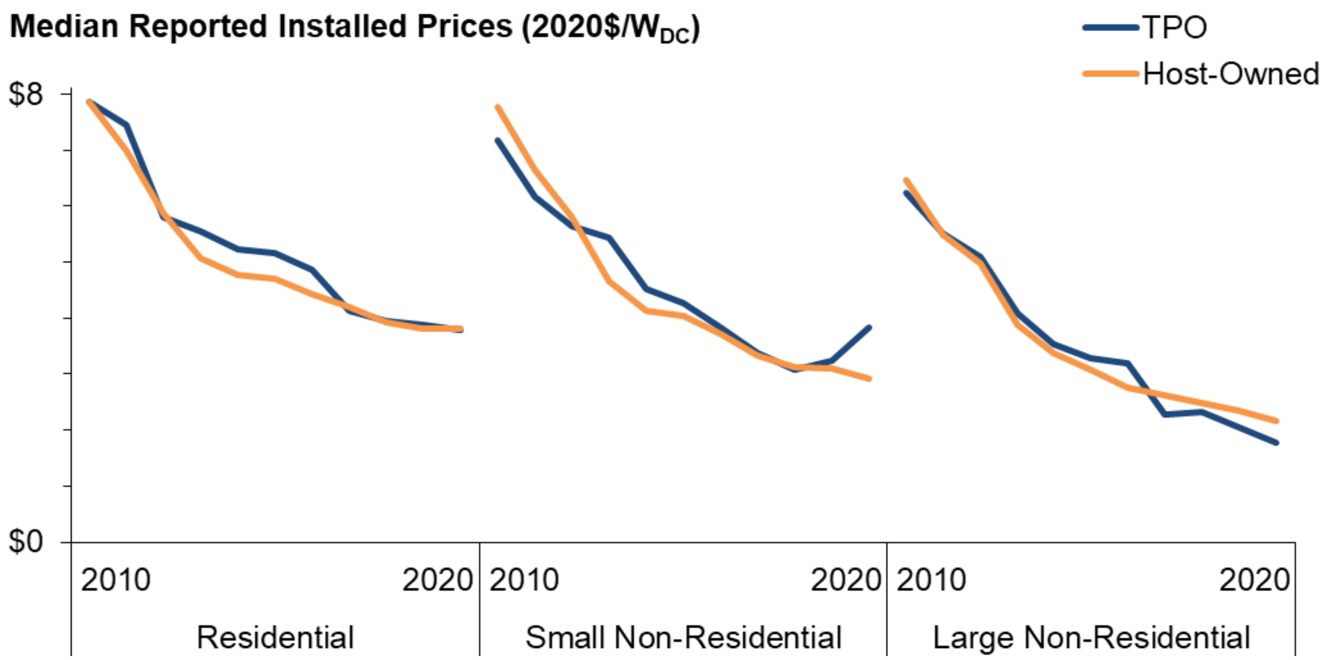


Notes: Installed prices for countries other than the USA are from the International Renewable Energy Agency (IRENA)’s “Renewable Power Generation Costs in 2020” report and are derived from IRENA’s Renewable Cost Database. For the Non-Residential sector, data from IRENA generally refer to systems up to 500 kW in size, and thus encompass both the Small and some portion of the Large Non-Residential segment used within Tracking the Sun.

Side Bar: *Installed Prices Reported for TPO Systems*

- Depending on the particular project or firm, installed prices reported for TPO systems may represent:
  - An appraised value or fair-market value construct (as often used as the basis for federal tax credits)
  - An actual transaction price between the third-party financier and an independent installer, which may or may not reflect all soft costs
- As a precautionary step, pricing data reported for TPO systems are excluded from the installed-price analysis, on the grounds that they cannot be meaningfully compared to prices reported for host-owned systems
- Nevertheless, the data show that prices for TPO systems, in fact, correspond quite closely to those for host-owned systems

Installed Prices for TPO vs. Host-Owned Systems

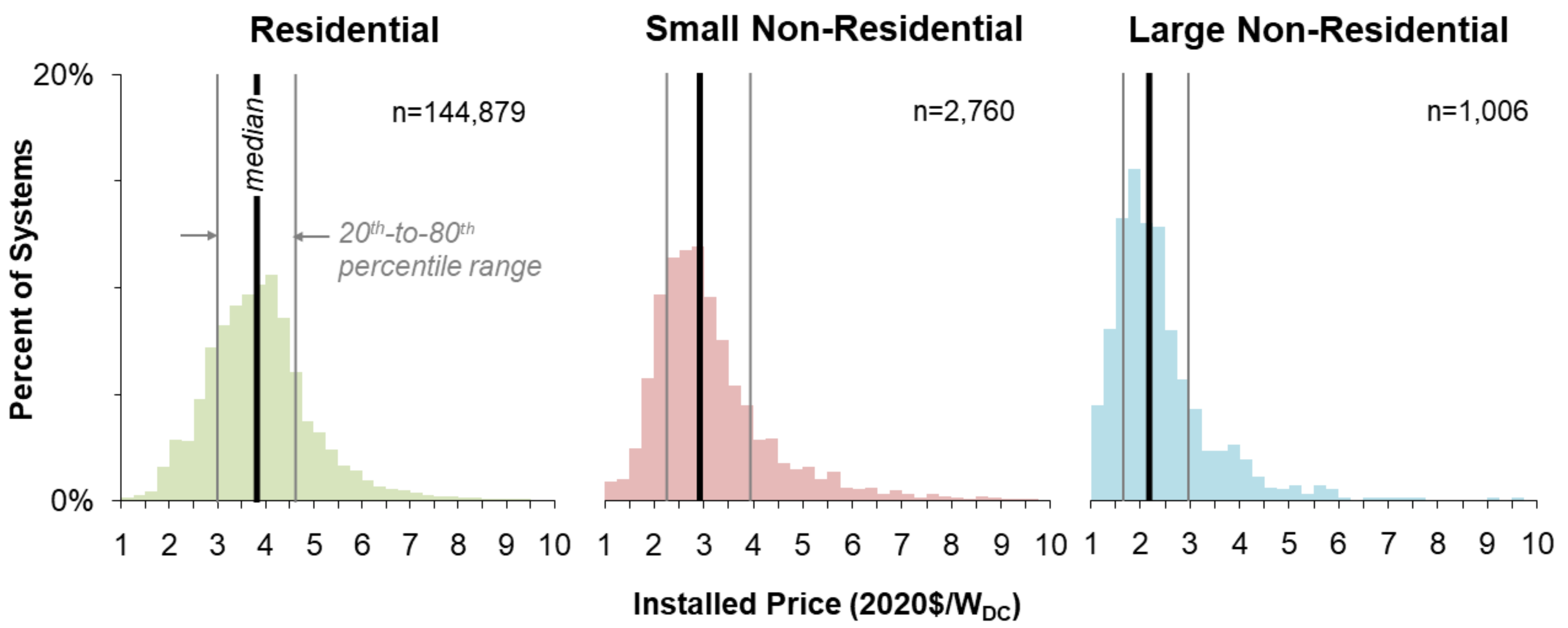


Note: TPO systems not otherwise included in installed-price analysis; figure above for reference only

Variation in Installed Prices

Installed-Price Variation Across Systems

Installed-Price Distribution for Systems Installed in 2020



20th-to-80th Percentile Bands for Systems Installed in 2020

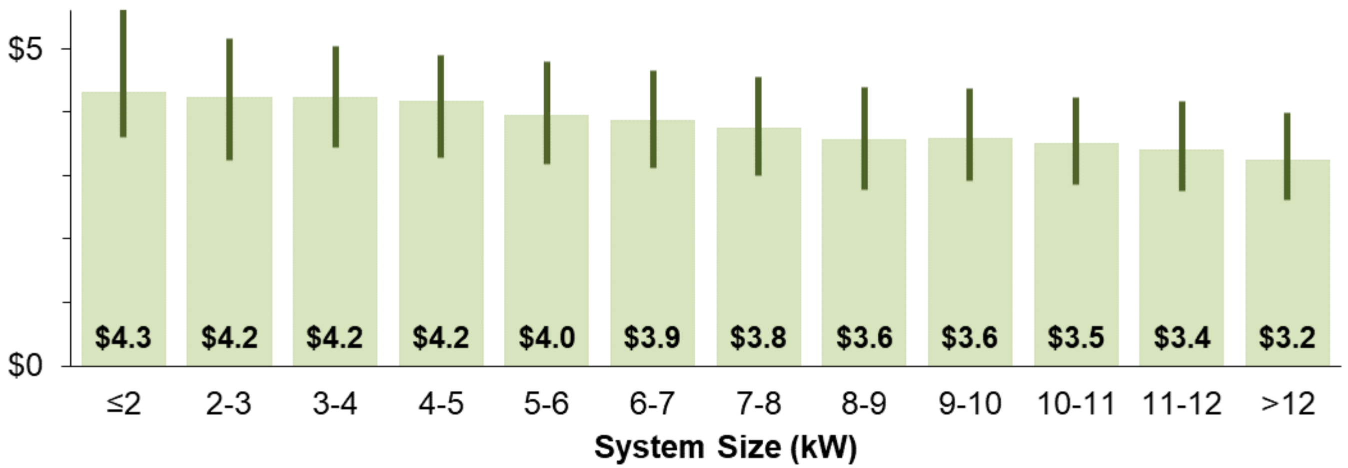
- \$3.0/W - \$4.6/W (residential)
- \$2.3/W - \$3.9/W (small non-residential)
- \$1.7/W - \$3.0/W (large non-residential)

- Wide pricing variability has persisted over time, despite continuing maturation of the U.S. PV market
- Reflects underlying differences in:
  - Project characteristics
  - Installer attributes and pricing strategy
  - Features of the local market, policy, and regulatory environment
- We explore a subset of pricing drivers in the following slides, through both descriptive analysis and a multi-variate regression model
  - Numerous other studies have also investigated pricing drivers, often leveraging TTS data

Economies of Scale for Residential and Non-Residential Systems

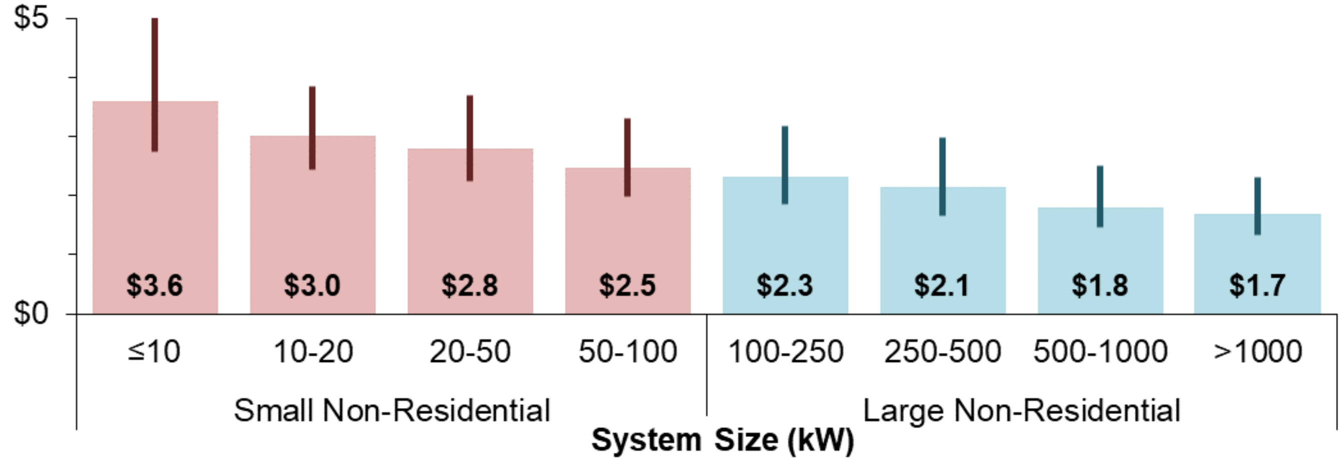
Residential Systems Installed in 2020

Median Installed Price and 20th/80th Percentiles (2020$/$W_{DC}$)



Non-Residential Systems Installed in 2020

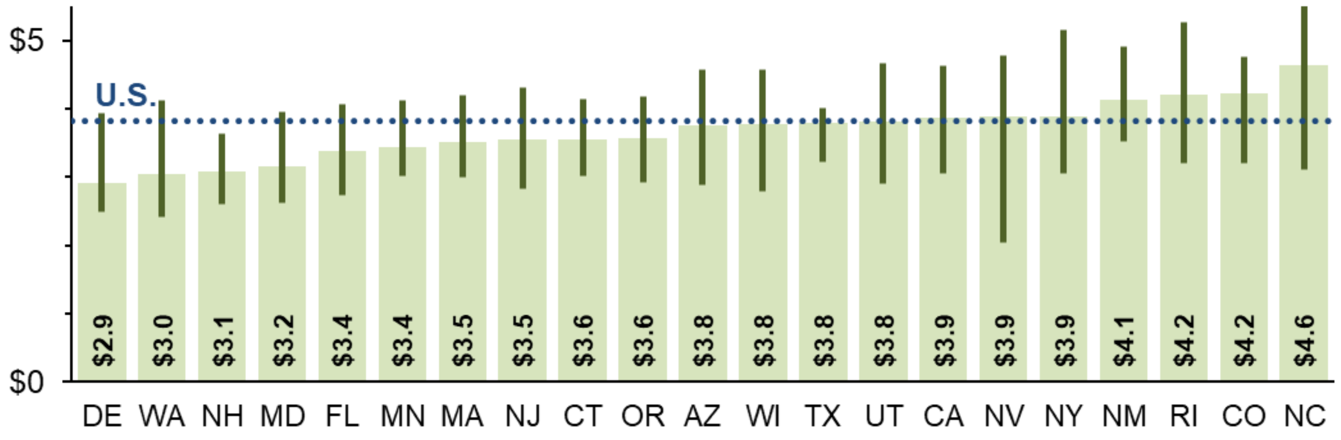
Median Installed Price and 20th/80th Percentiles (2020$/$W_{DC}$)



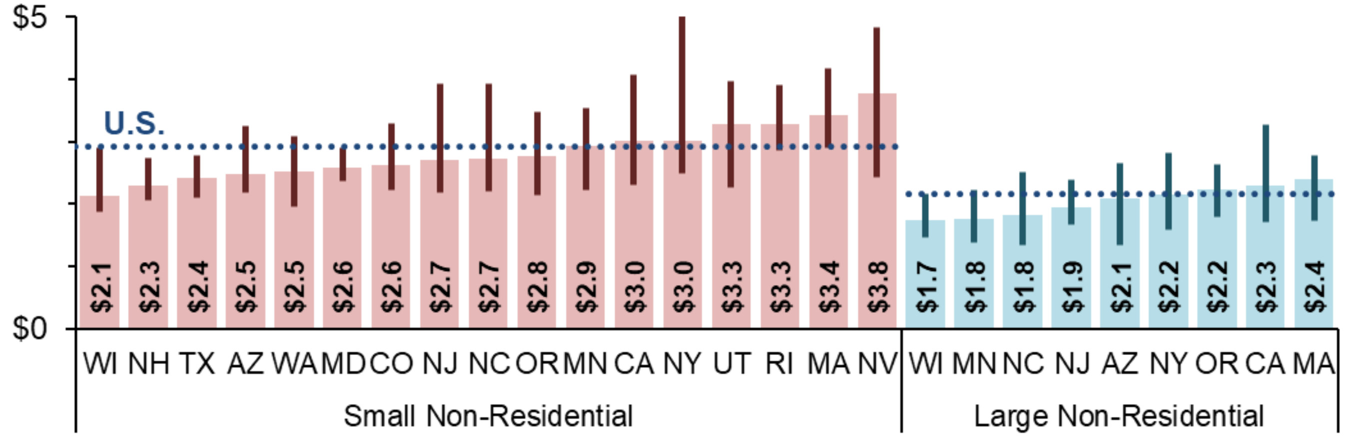
- Among residential systems installed in 2020, median prices were roughly $1/W lower for the largest (>12 kW) systems compared to the smallest (≤2 kW) systems
- Later regression analysis suggest that differences in system size are among the largest single drivers for pricing variability across residential systems, though quite a bit of variability clearly exists among systems of the same size
- Among non-residential systems, which span an even wider size range, median prices were ~$2/W lower for systems >1,000 kW, compared to the smallest non-residential systems ≤10 kW (keeping in mind that ground-mounted systems in this report are capped at 5 MW_{AC})

State-Level Differences in Installed Prices

Residential Systems Installed in 2020



Non-Residential Systems Installed in 2020

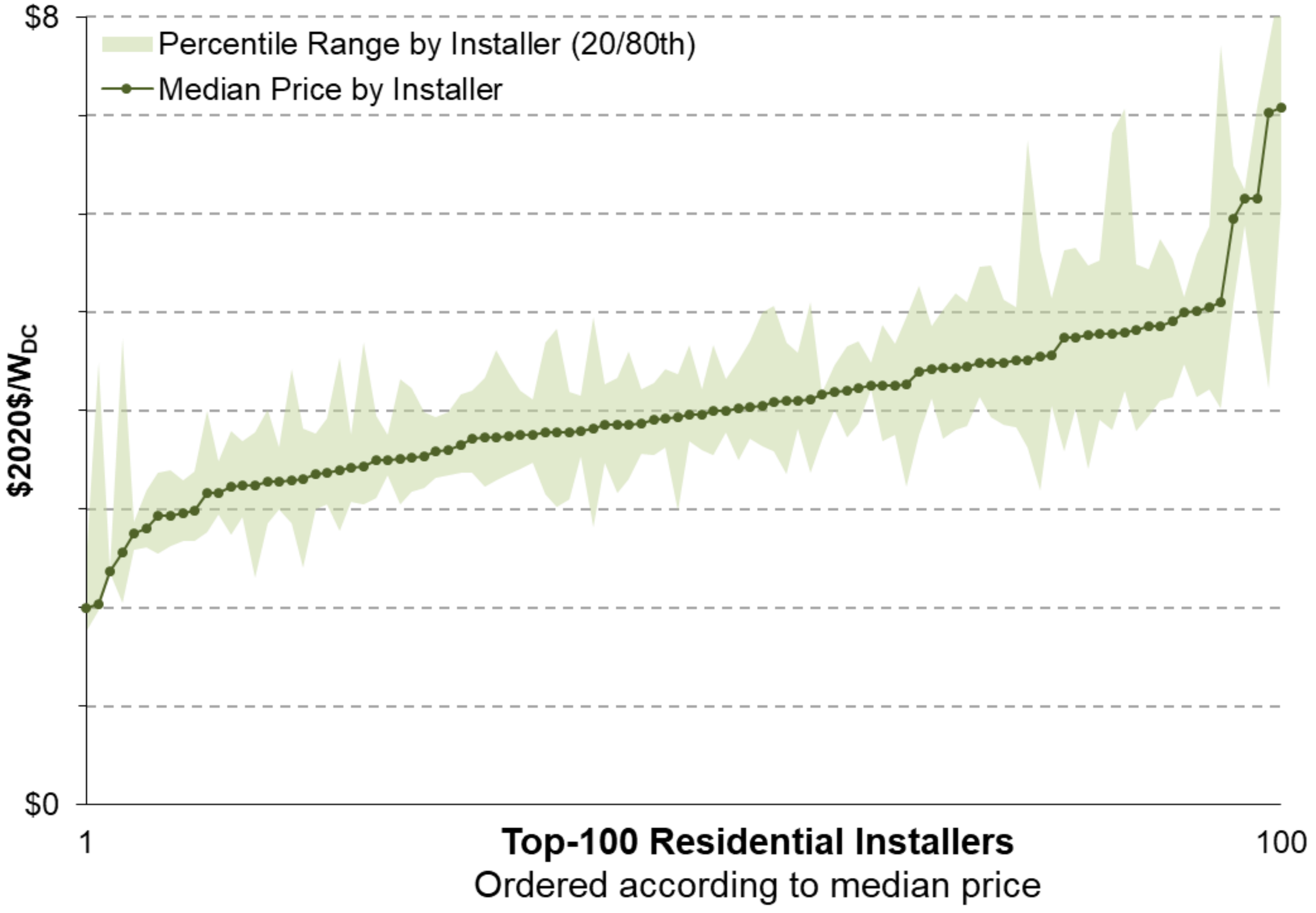


- Median prices vary substantially across states within each of the customer segments; among residential systems, for example, median prices in 2020 ranged from $2.9/W in DE to $4.6/W in NC.
- Note that prices in CA are relatively high, pulling overall U.S. median prices upward, but most states exhibit lower prices
- Cross-state pricing differences reflect both 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, 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 2020



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 the tails, median prices across the top-100 residential installers in 2020 ranged from $3.0/W to $5.0/W, with half of these installers registering median prices above $4.0/W
- Differences across installers can reflect features of the markets in which each firm operates as well firm-level attributes.
- For example, as the later regression analysis shows, firms with more cumulative experience generally have lower prices, though those differences are generally small ($0.02/W per 1,000 systems installed)
- A significant amount of pricing variability also occurs across systems among individual installers, with most installers exhibiting a percentile band of at least $1.1/W around their respective median

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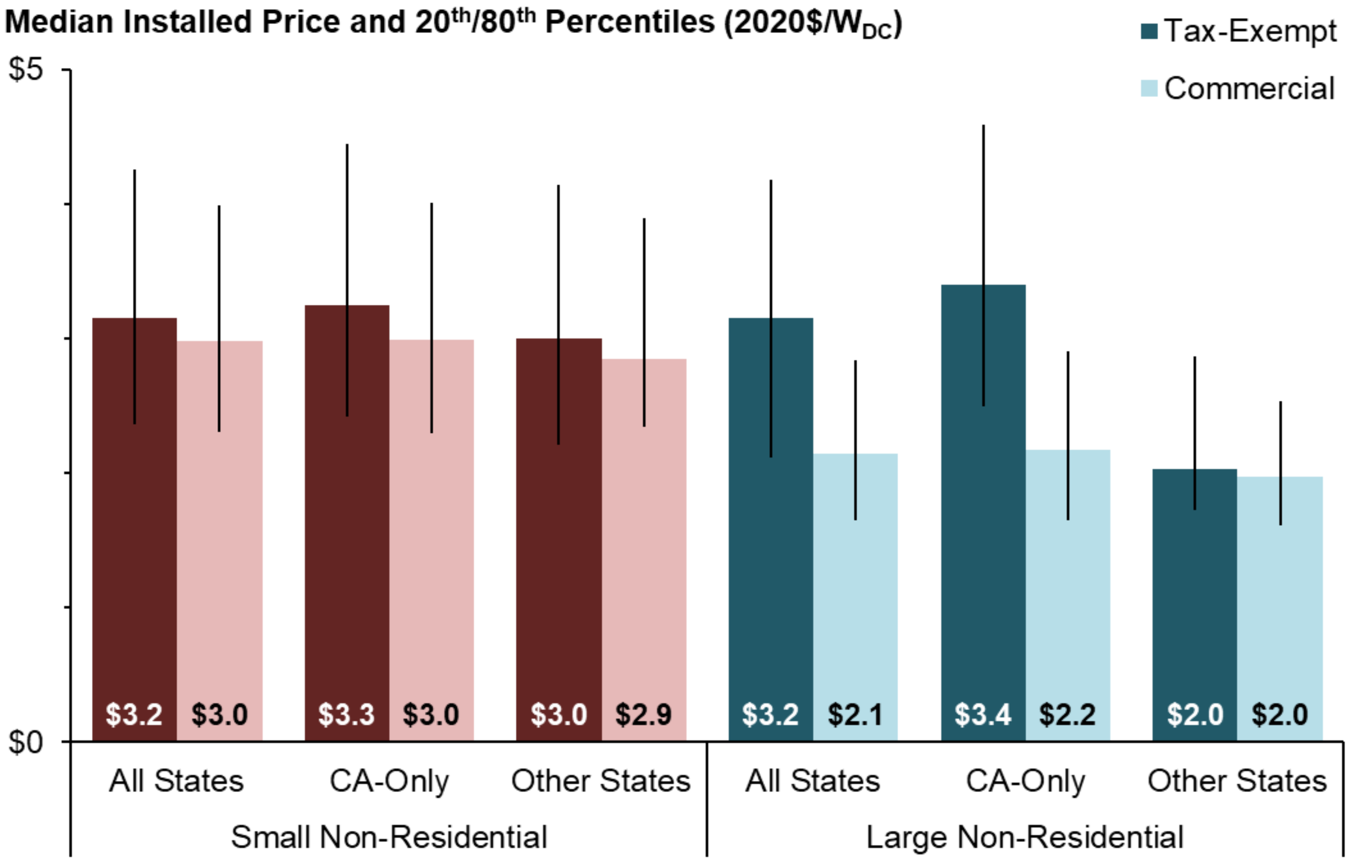
Installed-Price Differences by Non-Residential Customer Type

Tax-Exempt vs. Commercial Non-Res. Systems in 2020

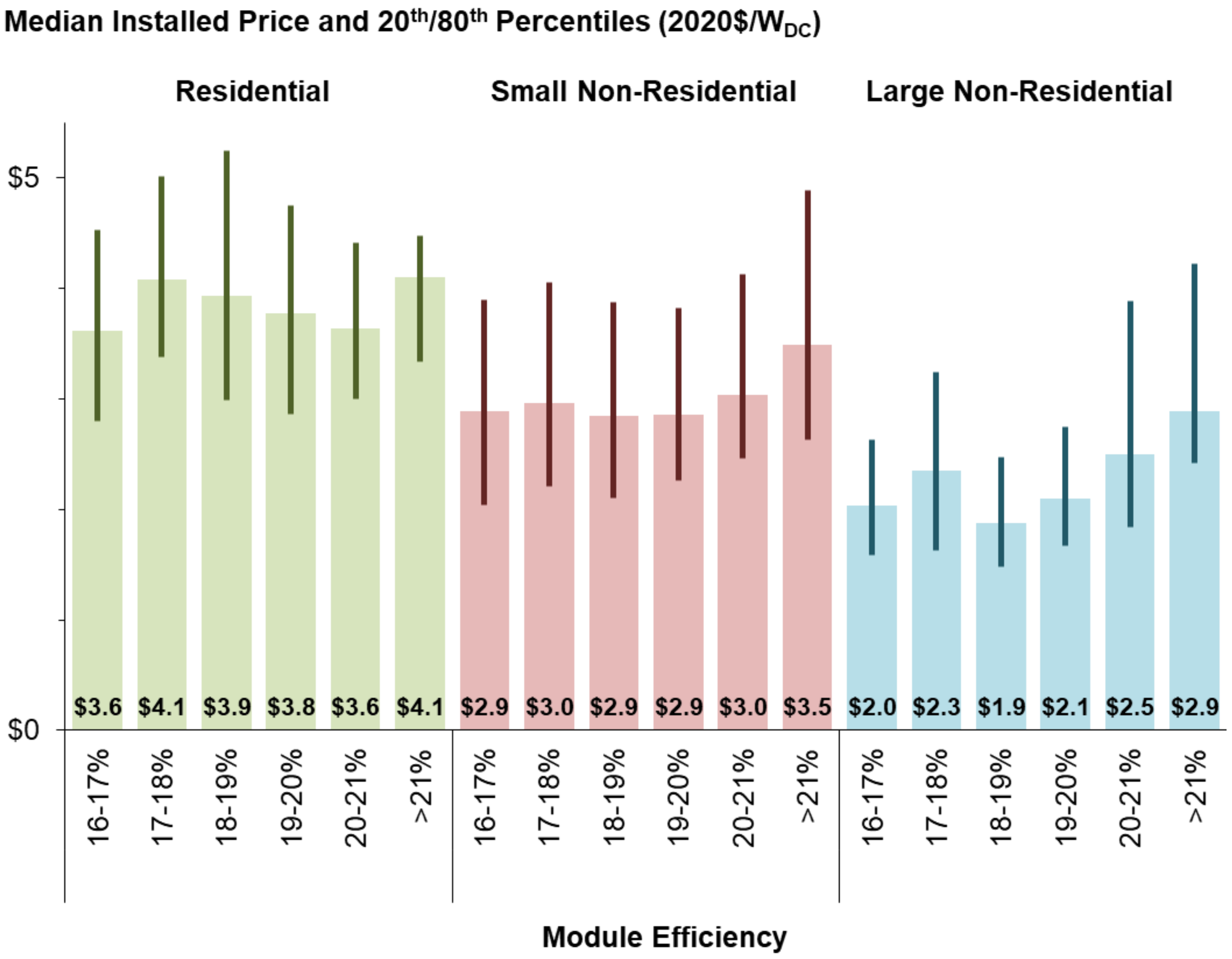


Notes: Summary statistics are based on a somewhat narrow subset of data providers who provide customer segmentation details for non-residential systems.

- Installed prices are generally higher for tax-exempt site hosts (schools, government, non-profits), compared to prices for commercial site hosts
- Differences are most pronounced among large non-residential systems and in California ($3.4/W vs. $2.2/W)
- Higher prices for systems at tax-exempt customer sites may reflect a number of possible characteristics of tax-exempt customers, for example:
  - prevailing wage/union labor
  - requirements for domestically manufactured components
  - prevalence of shade or parking structures
  - lower borrowing costs (enabling higher-priced systems to pencil-out)

Installed-Price Differences by Module Efficiency

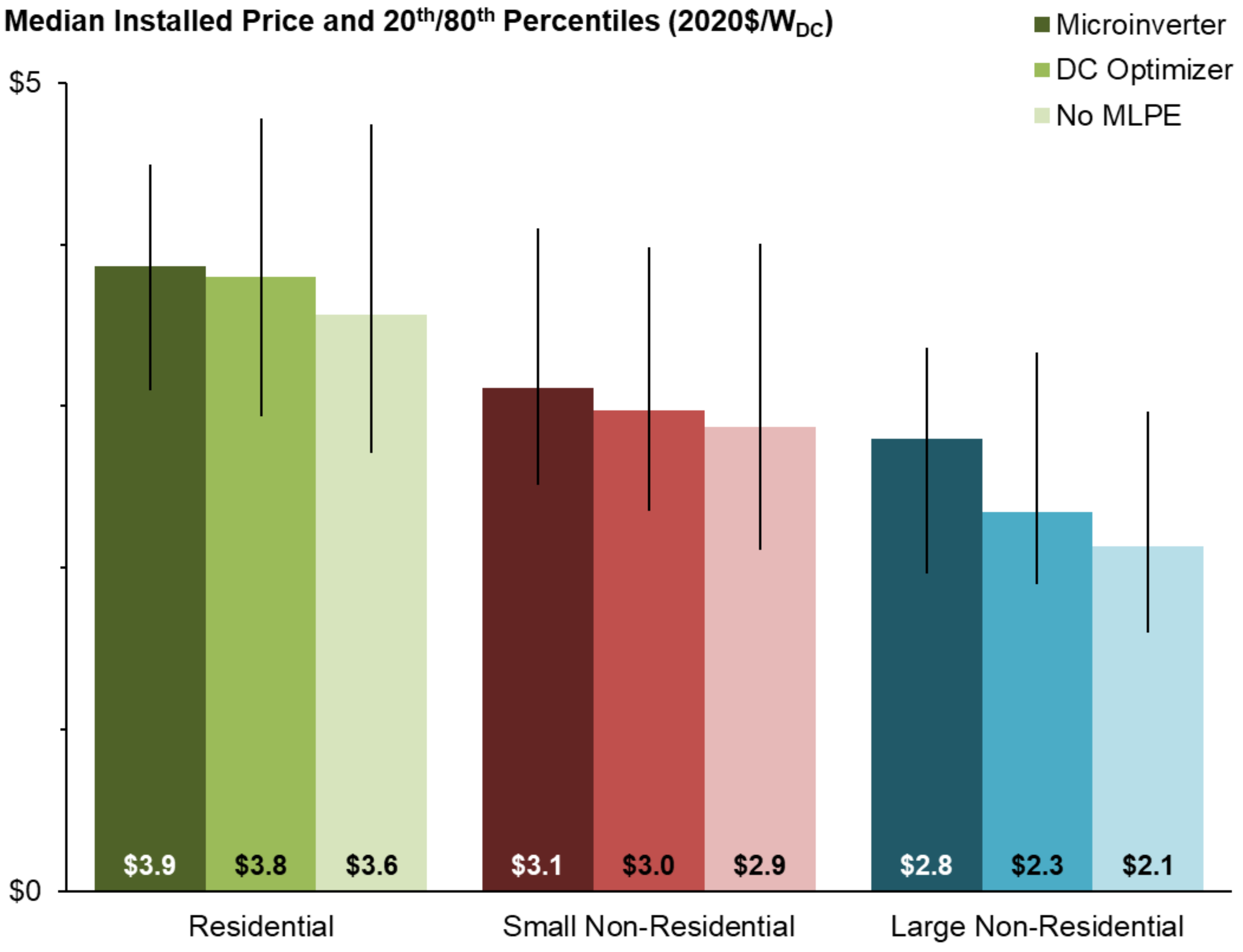
Installed Prices by Module Efficiency for 2020 Systems



- Higher efficiency modules can sell at a premium, but may also allow for savings on BoS costs
- Residential installed prices show no clear trend with module efficiency, though later regression model shows that systems with module efficiencies >21% tend to cost $0.15/W more, on average, after controlling for other factors
- Non-residential systems also show a clear rise in pricing for systems with higher efficiency modules
- Almost all modules in the dataset with >21% efficiency are n-type mono-crystalline modules by SunPower or LG, which often sell at a substantial premium over lower efficiency mono modules

Installed-Price Differences by Inverter Technology

Installed Prices for 2020 Systems with and without MLPEs



- Installed-price differences by inverter technology type are small, but show a consistent pattern across all three customer segments
- In particular, installed prices are highest for systems with microinverters, lower for those with DC optimizers, and lowest for those without any MLPEs
- For example, among non-residential systems, median installed prices were $3.9/W for microinverter systems, $3.8/W for systems with DC optimizers, and $3.6/W for those without any MLPEs; non-residential systems exhibit similar trends
- Later regression analysis results also show higher prices for systems with MLPEs, but the order is reversed, with the largest price premium for systems with DC optimizers, and a somewhat smaller premium for systems with microinverters

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Econometric Analysis of Pricing Variability

2020 Host-Owned Residential Systems

Econometric Model Overview and Results

- We use a multi-variate linear regression to estimate the effects on PV prices from various system, market, and installer characteristics; the model also includes state and quarterly fixed effects variables
- Supplements preceding descriptive analysis by showing how individual factors affect installed prices, while holding all other factors constant
- Focuses in this edition of the report on host-owned, residential, stand-alone PV systems installed in 2020
- The coefficients in the table to the right represent the average change in PV system price ($/W) given a unit change in each of the variables listed (or, for binary variables, if that variable is true); see Appendix for further discussion of these results
- For further details on the model specification and variable definitions, please see Barbose, Darghouth et al. (2019)**

Variable	Coefficient
System size (kW)	-0.21*
System size squared	0.01*
Premium efficiency module (>21%)	0.14*
Microinverter	0.14*
DC optimizer	0.24*
HHI (market concentration)	-0.01
HHI squared	0.34*
Market size (x1,000)	-0.03*
Installer experience (x1,000)	-0.02*
Population density (x1,000)	0.05*
Median income (x10,000)	-0.03*
New construction	-0.08*
Groundmount	0.40*
N	123,589
R^2	0.12

* p<0.05

**The only change from the approach outlined there is that the threshold for defining premium efficiency modules was increased from 20% to 21%.

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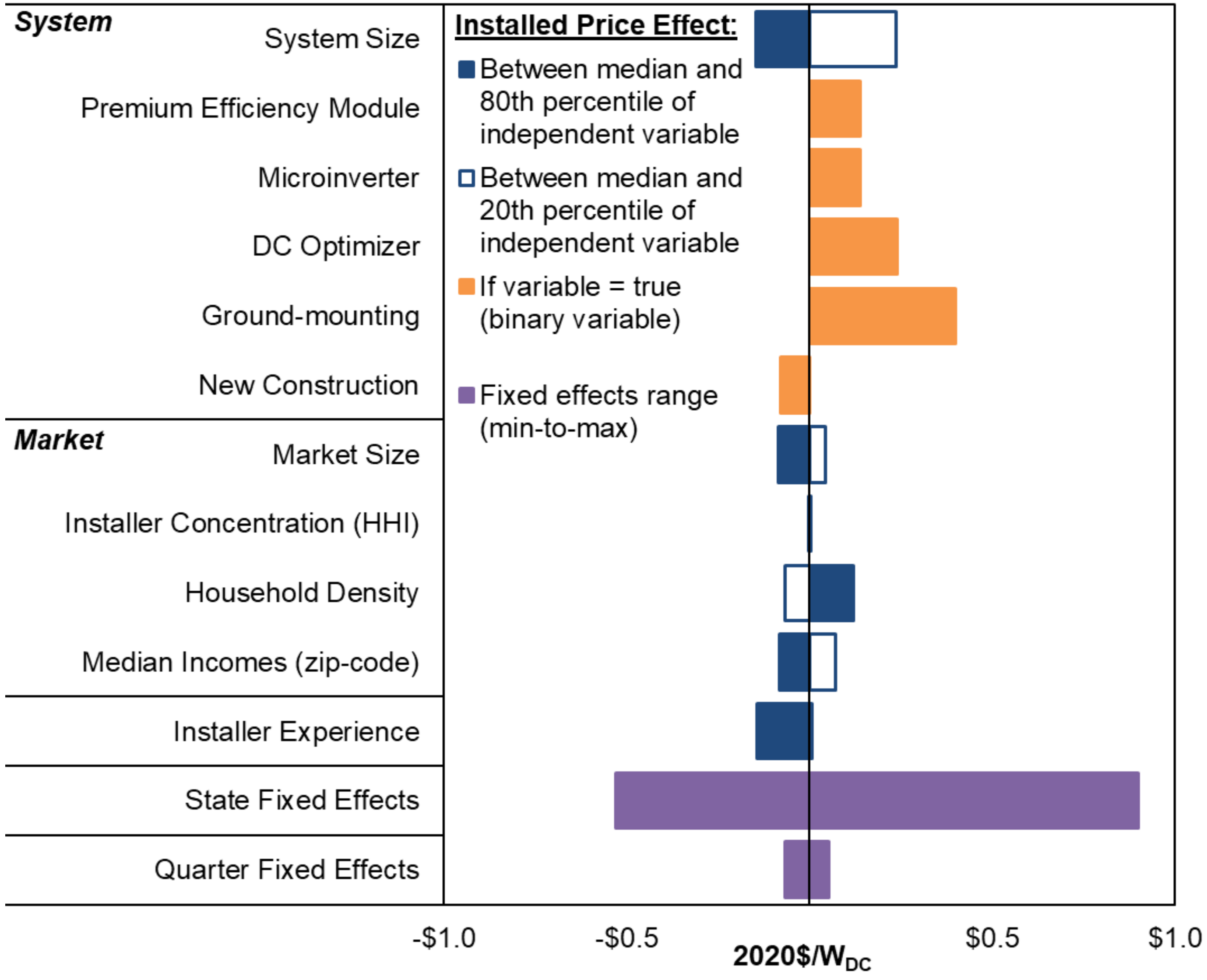
Sensitivity of Installed Prices to Modeled Drivers

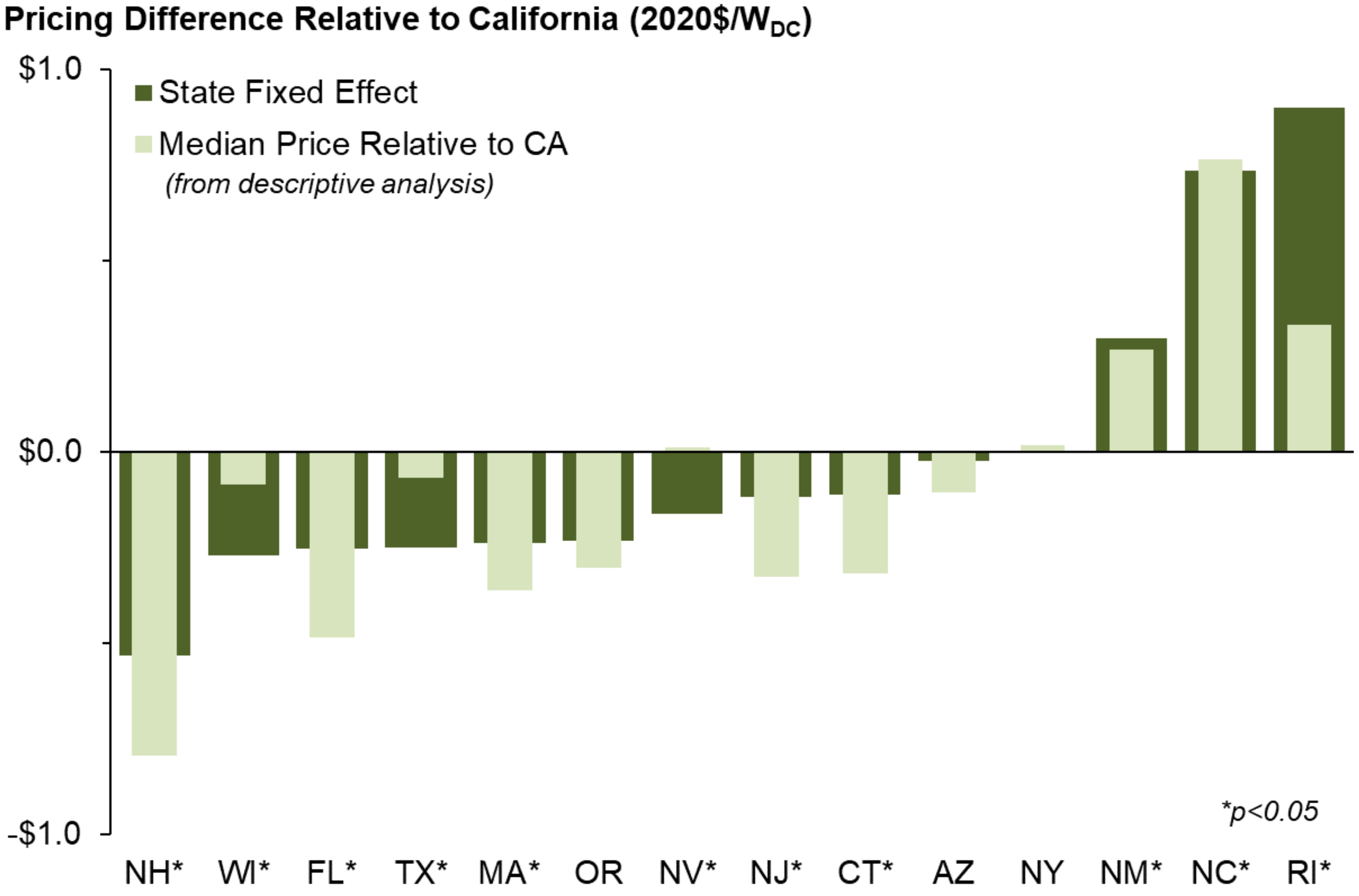
- Of the system-level pricing drivers, the largest effects are associated with system size ($0.38/W range between the 20-80th percentile sizes) and ground-mounting (+$0.40/W)
- Effects are smaller for premium efficiency modules (+$0.14/W), microinverters (+$0.14/W), DC optimizers (+$0.24/W), and new construction (-$0.08/W)
- Effects associated with the various market- and installer-related drivers are all relatively small (<$0.2/W), but in general are directionally intuitive (e.g., lower prices in larger markets and for installers with more experience) and consistent with prior research
- Of particular note is the wide range across the state fixed-effects variables, 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 State-Level Pricing Differences After Controlling for Other Factors*

State Fixed Effects Compared to Difference in Median Prices



- State fixed effects represent difference in average price relative to California, after controlling for other variables
- Fixed effects are generally smaller than the pricing differences from the descriptive analysis, indicating that some of those price differences are related to the modeled pricing drivers
- That said, sizeable state fixed effects remain: most states are within a ~$0.3/W band, but a few states exhibit much greater fixed effects
- Some of that may reflect the impact of significant unobserved pricing drivers, beyond the modeled variables; some of that may also be idiosyncratic (e.g., exceptionally high pricing by a few large volume installers states, as in RI)

For more information

Download the report, data, and other related materials:
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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 Public Utilities Commission
CA Center for Sustainable Energy (Bear Valley Electric)
CA Center for Sustainable Energy (PacifiCorp)
CA City of Palo Alto Utilities
CA Imperial Irrigation District
CA Los Angeles Department of Water & Power
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 Department of Commerce & Economic Opportunity
IL Power Agency
MA DOER
MA Clean Energy Center
MD Energy Administration
ME Efficiency Maine
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 Department
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 CPS Energy
TX Frontier Associates
UT Office of Energy Development
VA Department of Mines, Minerals and Energy
VT Energy Action Network
VT Energy Investment Corporation
WA Puget Sound Energy
WA Washington State University
WI Focus on Energy

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Further Discussion of Regression Results

- **System size:** The negative coefficient on system size suggests that prices are generally lower for larger systems, consistent with economies of scale. The positive coefficient on system size square indicates that this effect is diminishing.[a]
- **Equipment:** The model suggests that installed prices are generally higher for systems with premium modules (>21% efficient), microinverters, or DC optimizers.
- **Market structure:** The negative coefficient on HHI (a measure of market concentration) shows that prices are generally lower in more concentrated markets, meaning markets where a relatively small number of installers holds more market share. However, the positive coefficient on HHI squared shows that prices are generally higher in very concentrated markets.[b]
- **Installer experience:** The model indicates that more experienced installers are associated with lower system prices, consistent with economic theory that suggests that experience results in lower costs.[c]
- **New construction:** The model suggests that prices are generally lower for systems installed during new home construction, consistent with findings from previous research.[d]

Additional Resources

For further reading on analyses of PV prices related to these findings, see: a) “Deconstructing Solar Photovoltaic Pricing.” 2016. The Energy Journal; b) “Non-monotonic effects of market concentration on prices for residential solar photovoltaics in the United States.” 2020. Energy Economics. ; c) “Learning-by-Doing in Solar Photovoltaic Installations.” 2019. Yale. ; and d) “Solar Economies of Scope through the Intersection of Four Industries.” 2018. NREL.