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Research Article

Patience is a virtue: A data-driven analysis of rooftop solar PV permitting timelines in the United States

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ABSTRACT

Local permitting can ensure the safe installation and operation of rooftop solar photovoltaic (PV) systems. At the same time, burdensome local permitting processes and local variation in requirements may pose challenges to PV deployment. In this article, we explore new data on the durations between key steps in the PV permitting process in the United States. The data suggest that a typical customer can expect to wait around 25–100 days from permit application until an installed system passes inspection. Permit durations vary significantly across jurisdictions, due in part to differences in local permitting policies. However, permit durations vary as significantly within jurisdictions as across them, in part due to significant variation across installers, suggesting that installer strategies and practices play an important role in permitting timelines. Permit durations have declined over time, reflecting progress from permit streamlining policies and jurisdiction learning-by-doing, though durations have stabilized in recent years. The data suggest that typical PV customers still face long and uncertain permitting timelines in the United States.

1. Introduction

In the United States, rooftop solar photovoltaic (PV) systems generally require a permit from a local building, electrical, or other permitting authority (Stanfield et al., 2013). Local permitting requirements may ensure safe PV system installation and operation given local contexts (Stanfield et al., 2013; CA OPR, 2019). At the same time, local PV permitting processes can pose challenges to PV deployment. Onerous local permit requirements can increase the amount of customer and PV system installer time required to navigate the permitting process. Further, variations in local permitting processes can force installers to invest time and effort to learn the nuances of numerous local policies (Argetsinger and Inskeep, 2017; Strupeit, 2017). These permitting burdens may affect customer experiences (Sinitskaya et al., 2019), translate to higher system prices (Dong and Wiser, 2013; Burkhardt et al., 2015), and ultimately result in lower PV adoption rates (Hsu, 2018; White, 2018).

Several state, regional (e.g., county level), and local (e.g., city level) initiatives are underway to reduce PV permitting burdens in the United States, generally through streamlining permitting processes (e.g., online applications, virtual inspections) and increasing standardization across jurisdictions (Stanfield et al., 2012; Stanfield et al., 2013; Taylor, 2019). At the national level, the U.S. Department of Energy-funded SolSmart program recognizes solar-friendly jurisdictions and provides technical assistance to jurisdictions seeking to reduce permitting timelines. Further, The Solar Foundation, the Solar Energy Industries Association, and the U.S. National Renewable Energy Laboratory are developing the Solar Automated Permit Processing Campaign to create free online permitting tools and other assistance to streamline local permitting processes. However, no data-driven studies are available that quantify PV permitting burdens in terms of the durations of permitting processes. Without such research, it is difficult to discern the historic or potential future impacts of these initiatives to reduce PV permitting burdens.

In this article, we fill this research gap with data-driven analysis of PV permit durations from a new data set of PV permits in the United States. Our article is motivated by four research questions: 1) How long is a typical PV permit process from application to completion? 2) How much do these durations vary? 3) What are the key trends in PV permit durations over space and time? and 4) What factors can explain variation in permit durations? By answering these questions, our article can inform future research to identify policy and market measures to reduce permit durations.

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The U.S. provides a particularly rich research context for these questions. The U.S. has no national-level standardization of PV permitting requirements (Seel et al., 2014). Most states set minimum permitting requirements and delegate authority to sub-state jurisdictions to implement permitting processes and to develop stricter requirements as needed. As a result, the U.S. PV permitting landscape is a patchwork of locally developed and implemented processes (Stanfield et al., 2013). While the United States provides a rich context for research purposes, we note that permitting timelines in the United States may not be representative of timelines in other contexts, particularly in countries with more national-level standardization of permitting requirements (e.g., Germany).

The remainder of the article is organized as follows. First, we provide a review of the relevant literature in Section 2. We describe our data and methods in Section 3. In Section 4, we present descriptive trends in PV permit durations. In Section 5, we present the results of a duration analysis model to explore how various factors affect PV permit durations. We discuss the implications of key results in Section 6.

2. Literature review

Several studies document the PV permitting practices of local authorities having jurisdiction (AHJs) (Stanfield et al., 2012; Stanfield et al., 2013; Cook et al., 2016; Argetsinger and Inskeep, 2017; Taylor, 2019). This literature elucidates three findings relevant to our article: 1) AHJs have generally integrated PV installations into existing permitting processes—particularly building and electrical permitting; 2) these permitting process vary across AHJs; and 3) some AHJs have implemented measures to expedite permitting for small-scale (e.g., <10 kW) PV systems or to otherwise facilitate PV permitting. Cruz (2018) finds that various political factors explain why some AHJs adopt measures to facilitate PV permitting while others do not, such as AHJ membership in climate change networks and whether AHJs have dedicated sustainability staff.

Several studies have quantified PV permit process durations. Ardani et al. (2015) use residential PV installation data to estimate that an average rooftop PV system takes 6 days to pass permitting inspections. That study as well as Barnes (2015) quantify durations for processes to interconnect PV systems to the grid—though those processes are outside the scope of our article. Three studies have explored PV permit durations qualitatively through surveys. Using survey data from the U.S. Department of Energy's Rooftop Solar Challenge, Taylor (2019) finds that more than half of AHJs issue a permit within 3 days from application, on average. Based on a survey of California AHJs, Salmon et al. (2014) find that AHJs implemented measures to reduce permit durations from 2007 to 2009, but that durations stabilized after those initial efforts. The authors posit two explanations for the stabilization of permit durations: 1) Increasing application volumes met or exceeded AHJ capacity to process those applications; and 2) AHJs learn to permit PV more efficiently through experience, but average permit processing times can still remain relatively high as long as some AHJs remain inexperienced. Stanfield et al. (2013) describe permit durations based on several AHJ-level case studies. The authors find significant variation across and within AHJs in terms of permit durations. For instance, the authors find that permit application reviews can take between 1.5 and 30 days.

Several studies explore the effects of PV permitting on system prices. Burkhardt et al. (2015) find that PV customers in jurisdictions with the most onerous permitting processes pay $0.18 per watt ($/W) more than PV customers in jurisdictions with the least onerous permitting, roughly a 3% difference based on prices during the study period. Dong and Wiser (2013) show that differences in city-level permitting processes are associated with price impacts ranging from $0.27/W to $0.77/W. In a meta-analysis, Beck and Rai (2020) find that permitting-related costs account for 3–7% of all non-hardware PV installation costs in the United States. Seel et al. (2014) find that permitting costs are about $0.21/W higher in the United States than in Germany. In Germany, many permitting requirements are set at the national level, reducing jurisdiction-level inconsistency. Further, many German jurisdictions have chosen to exempt small-scale PV systems from building permitting requirements, further reducing permitting costs in Germany relative to the United States (Strupeit, 2017).

Research on the links between local permitting and PV deployment has yielded mixed results. White (2018) compares the number of new PV systems installed annually in AHJs with and without streamlined permitting provisions and finds no statistically significant relationship. Hsu (2018) compares cumulative PV deployment in California AHJs that had adopted a state-mandated PV approval procedure with AHJs that had yet to adopt the procedure. The study produces mixed results based on different model specifications, but the author concludes that cumulative PV deployment in AHJs with the PV approval procedures was 22% higher than in AHJs without the procedures while controlling for other factors.

Sinitskaya et al. (2019) explore how various components of the PV adoption process affect the subjective experiences of PV adopters and installers. The study identifies permit applications and inspection requests as specific "pain points" for PV installers. The authors posit that these pain points may delay adoption. However, the study does not attempt to quantify the magnitude of the impacts of permitting processes on PV adoption durations.

Our article builds on this literature in two ways. First, we build on previous descriptions of permit process durations (Stanfield et al., 2013; Salmon et al., 2014; Ardani et al., 2015; Taylor, 2019) using a significantly larger and more geographically-comprehensive system-level data set. Second, we build on the survey-based results of Sinitskaya et al. (2019) with a data-driven analysis of the factors that determine PV permit durations.

3. Data and methods

PV permitting records were obtained from BuildZoom, an online marketplace that connects home and business owners to service contractors including PV installers. The BuildZoom data include dates for three key events in the permitting process: the date the permit application was submitted, the date the permit was issued, and the date the installed system passed the permitting inspection (Fig. 1). BuildZoom provided over 1.4 million records of permits for rooftop PV systems, though only about one third of those records include valid application dates, permit issuance dates, and passed-inspection dates.[1] The raw data included records with application dates spanning more than two decades. However, the sample sizes in the early years of the data are relatively small, and observations in the early years of the data are likely not representative of current permitting processes. We therefore focus on a subset of the data with an application date in 2010 or later—though we include older records in certain analyses of time trends, where noted. Observations of permit durations are truncated in that passed-inspection dates are unavailable for permits that had yet to pass inspection when the data were generated. To prevent data truncation from introducing bias into the analysis of temporal trends, we limit the data to permits that lasted no more than 1 year from application to passed inspection and dropped records with an application date before March 6, 2018, representing the date 1 year before the most recent application date reported in the data. We assume that multiple records filed on behalf of the same property within the same month represent duplicative records and drop those records. We dropped records with implausible recorded dates where the permit was issued before the application date or the permit passed inspection before the permit was issued. Finally, we

[1] PV systems have a variety of applications. Our scope is limited to rooftop PV systems. We dropped records where the record description indicated that the permit represented a ground-mounted PV system, solar water heating system, PV-powered attic fan, PV-powered pool heater, and/or PV-powered billboard.

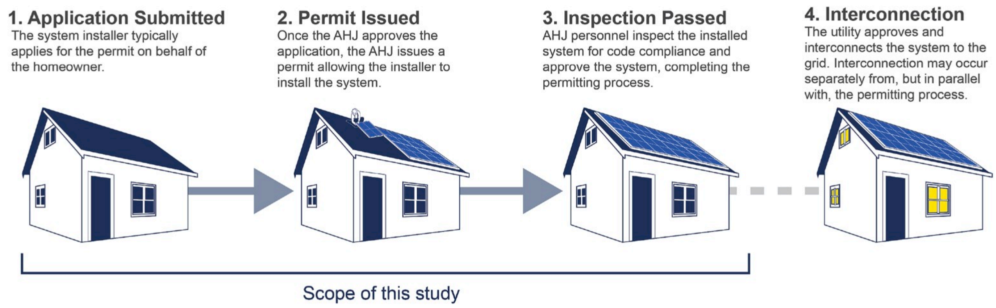

Fig. 1. The PV permitting and interconnection process.

dropped records associated with PV systems installed as part of a new home construction, given that numerous extraneous factors associated with the home construction process affect permit durations for those records.

These data cleaning processes yield a final data set of 203,590 records on 178,393 unique properties in 368 AHJs[2] with application dates from 2010 to 2018. The key metrics in our analysis are the durations between permit application, permit issuance, and a passed inspection. We refer to these durations as apply-issue, issue-pass, and apply-pass (Fig. 2). We report central tendencies for the durations in terms of medians rather than means because the permit duration distributions are highly right-skewed. We report variation in permit durations in terms of inter-quartile ranges.

Our methodological approach is framed around our four research questions: 1) How long is a typical PV permit process from application to completion? 2) How much do these durations vary? 3) What are the key trends in PV permit durations over space and time? and 4) What factors can explain variation in permit durations? We answer the first three research questions through multiple descriptive analyses presented in Section 4. To answer the fourth research question, we develop a duration analysis model to test the effects of different factors on permit durations:

$$\log t_{ij} = \alpha + AHJ_j\beta_1 + job_{ij}\beta_2 + AHJ + INST + QTR + \varepsilon \tag{1}$$

where t_{ij} is the duration of one of the three permitting phases for record i located in AHJ j, α is a constant, AHJ_j is a vector of AHJ-level variables, job_{ij} is a vector of job-level variables, AHJ is an AHJ-level fixed effect, $INST$ is an installer-level fixed effect,[3] and QTR is quarter fixed effect. The AHJ- and job-level variables are defined in Table 1. The model represented by Equation (1) is an accelerated failure time (AFT) model, a specific model in the broader class of duration analysis models (Van den Berg, 2001). Amongst duration analysis models, the AFT model is relatively simple in that it does not require any assumptions on the baseline probability that a process ends in any given time period. Because this baseline probability is unspecified, the coefficients may be biased by unobserved variables that influence the process duration. However, it can be shown that AFT models provide robust evidence of the sign and significance of the effects of the observed factors (Van den Berg, 2001). Hence, we proceed with the AFT model as a means of understanding the direction and significance of the effects of various factors on permit durations, while noting that the magnitudes of the estimated coefficients should be treated with caution. We use robust AHJ-clustered standard errors in all models to control for the fact that the BuildZoom data were generated through a non-random sample of AHJs (Abadie et al., 2017).[4]

The model includes two variables to test the hypotheses posed by Salmon et al. (2014) to explain temporal trends in permit durations (see Section 2). First, the *experience* variable refers to the cumulative number of applications received by the AHJ associated with each record. This variable uses all records with application dates going back to 2000, otherwise following the same data cleaning protocol described in Section 3. The hypothesis is that AHJs "learn" to process permits more efficiently through experience. Process learning-by-doing is supported by a rich literature (Arrow, 1962), including in the PV context (Nemet, 2006; Bollinger and Gillingham, 2019). The learning hypothesis would be supported by a negative coefficient on the experience variable, suggesting that durations decline as AHJs accumulate more experience. Second, the *volume* variable refers to the number of applications received by the AHJ in the quarter associated with each record relative to the same quarter in the prior year. The hypothesis is that large application volumes can strain AHJ capacity to process those applications. That hypothesis would be supported by a positive coefficient on the volume variable, indicating that durations increase as AHJs face higher application volumes.

There are three limitations to note with the permitting data in this study. First, the data are not geographically representative of the U.S. PV market. The data have strong coverage in key markets like California and Hawaii but relatively weak coverage in other key markets such as Massachusetts, New Jersey, and New York. Second, the data's geographic composition has changed over time. In particular, Hawaii's share of the data declined significantly from 62% of records in 2012 to about 2% of records in 2018. The changing geographic composition of the data introduces additional data noise that affects the interpretation of temporal trends. We discuss these issues with our presentation of temporal results. Third, the data are generated through AHJ reporting processes. These reporting processes are not necessarily standardized. For instance, it is possible that AHJs with digital processes record and report the date of the application submission, while AHJs with analog processes record and report the date that the application was entered into a permit tracking system. Further, BuildZoom tends to collect data from AHJs with digital processes that facilitate data collection. As a result, the BuildZoom data may be biased toward AHJs with digital processes. A comparison of the BuildZoom data with permit duration data compiled by installers suggests that apply-issue durations may generally be downward biased in the BuildZoom data, while issue-pass durations are in line with the durations compiled by the installers. This comparison suggests that differences in AHJ reporting processes or biases in BuildZoom data collection may affect the representativeness of the data sample. We place several caveats on analyses concerning apply-issue durations throughout the article.

[2] For most records, the AHJ was identified as the authority that reported the permit to BuildZoom. Where the permit was reported by another party (e.g., installer), we assigned the records to AHJs according to the AHJ that reported other permits from the same city as the record. Where this matching was not possible, the city associated with the record was used as the AHJ.

[3] Each installer with at least 1000 records in the data was assigned a separate effect.

[4] The AFT models were estimated using the streg package for parametric survival models in Stata.

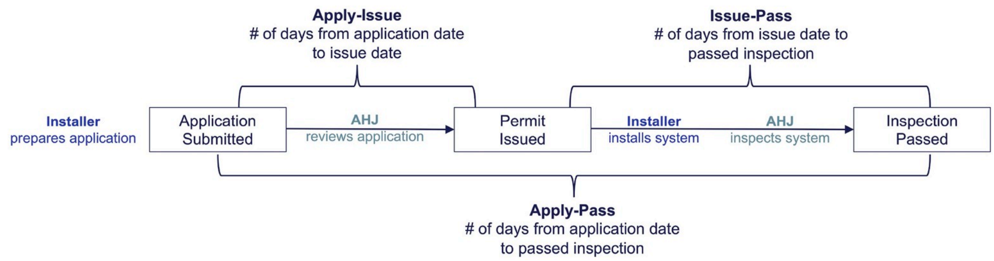

Fig. 2. Permit durations.

Table 1
Duration analysis model variables.

Variable	Definition	Rationale
AHJ Level Experience	The cumulative number of permit applications received by the AHJ associated with the record. Note: The experience variable is based on the cumulative number of applications received from 2000. The variable includes 10,901 records that were dropped from the descriptive analyses.	Negative coefficients would suggest AHJ-level learning-by-doing.
Volume	The number of permit applications received by the AHJ associated with the record in the same quarter in which the record's application was submitted relative to the same quarter in the prior year.	Positive coefficients would suggest that large application volumes—relative to the same volumes in the prior year—increase permit durations.
Installer cumulative experience	The cumulative number of permits associated with the system's installer *within* the AHJ.	Negative coefficients would suggest that installers learn to reduce permit durations through experience with a specific AHJ's processes.
SolSmart	Dummy variable for whether the AHJ is SolSmart designated (SolSmart = 1) or not (SolSmart = 0)	Negative coefficients would suggest that best-practice AHJ-level policies are associated with shorter permit durations.
Job Level		
Electrical	Dummy variable for whether the record includes an electrical permit	Tests whether electrical permits—and the additional job requirements they may reflect—affect permit durations.
Roofing	Dummy variable for whether the record includes a roofing permit	Tests whether roofing permits—and the additional job requirements they may reflect—affect permit durations.
Other	Dummy variable for whether the record includes an additional permit other than electrical or roofing	Tests whether non-related jobs (e.g., home remodel) implemented in tandem with PV installation affects permit durations.
Housing Age	Percentage of the housing stock that was built before 2000, based on zip code-level data from the U.S. Census	Tests whether the age of the housing stock affects permit durations.

Table 2
Permit duration quantiles (Days).

	Apply-Issue	Issue-Pass	Apply-Pass
Minimum	0	0	0
P25	0	20	26
Median	0	42	50
P75	9	85	97
Maximum[a]	357	364	364

[a] Recall that records with durations over 365 days were dropped from the analysis.

4. Descriptive statistics

At the median, the data suggest that a typical customer receives her permit on the same day as the application then waits 42 days until the installed system passes inspection (Table 2).[5] However, the data also suggest significant variation in permit durations. A typical customer can expect to receive her permit between 0 and 9 days from the permit application date, and then can expect to wait between 20 and 85 days for the system to pass inspection, based on 25th and 75th percentiles for those durations. In terms of the entire process, a typical customer can expect to wait 26–97 days from permit application to a passed inspection.

4.1. Durations across states and AHJs

Median state-level apply-pass durations in the data range from 33 days in Washington to 135 days in New York (Fig. 3).[6] California and

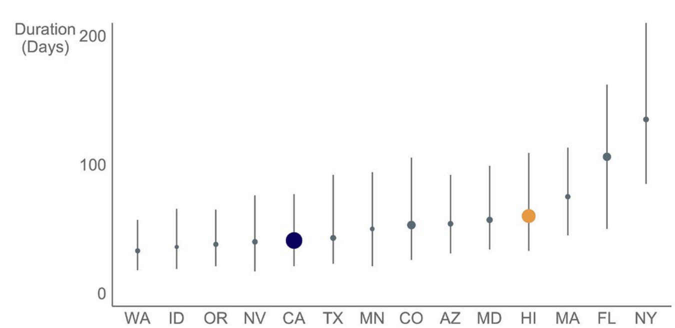

Fig. 3. Apply-pass median and inter-quartile ranges by state. Figure limited to states with at least 1000 records in data. The size of each point represents the state's share of the data.

[5] Same-day permits (e.g., permits with 0 days from apply-issue) may be overrepresented in the data, as noted in our discussion of data limitations in Section 3.

[6] It is worth recalling that the data are not necessarily geographically representative and the sample sizes from most states are relatively small. We therefore urge caution in the state-level comparison of permit durations.

Hawaii, which together account for about 74% of the dataset, drive durations in the dataset more than the remaining states. At the median, a typical permit in California takes 41 days from application to passed inspection while a typical permit in Hawaii takes 60 days. The relatively low permit durations in California may reflect state-level policies designed to streamline permitting processes (Salmon et al., 2014). California limits the ability of local AHJs to implement local solar ordinances. Further, since 2012, many California AHJs have adopted best practices developed by the California Governor's Office of Planning and Research. Finally, in 2014, California passed a state law requiring AHJs to adopt ordinances for streamlined permitting for small-scale PV systems (<10 kW) by September 30, 2015 (CA OPR, 2019). Other factors that could explain short durations in California include a relatively experienced installer base and a relatively stable climate that results in fewer weather-related installation delays than in states with more seasonal climates.

Permit durations vary significantly within states, in part because of variation across AHJs (Fig. 4). The observed AHJ-level variation is consistent with suppositions from the literature that inconsistent permitting requirements across AHJs could pose a barrier to PV deployment (Argetsinger and Inskeep, 2017; Strupeit, 2017). Even within California, the median AHJ-level apply-pass duration varies from 28 days to 80 days. However, apply-pass durations vary as significantly *within* as across AHJs. The AHJ-level interquartile range spans 63 days, on average, across the 100 AHJs depicted in Fig. 4. Put another way, a typical customer in any given AHJ faces an uncertain window of more than two months from permit application to a passed inspection. This within-AHJ variation is particularly remarkable given that all systems within an AHJ are, in theory, subject to the same permitting requirements. As highlighted later, variations in installation and permit timelines among PV installers represents one core driver for this within-AHJ variation.

Differences in local permitting policies could explain some of the variation across AHJs. To explore this hypothesis, we augmented the BuildZoom data set with additional data to test the effects of AHJ policies on permit durations. Our first additional data source is the list of AHJs recognized for their PV permitting best practices by the U.S. Department of Energy SolSmart program. By program design, AHJs apply for and—if meeting certain criteria—are recognized as gold, silver, or bronze, depending on their implementation of PV permitting best practices. The SolSmart program also recruits AHJs through conferences and various energy policy networks. A SolSmart designation provides evidence of AHJ implementation of best practices insofar as AHJs with such practices self-select into the program or SolSmart prioritizes recruitment of AHJs with such practices. However, it is possible that some AHJs in the data with similar best practices have not received a SolSmart designation. There are 81 SolSmart-designated AHJs represented in the BuildZoom data: 29 bronze-designated; 14 silver-designated; and 38 gold-designated AHJs. SolSmart designations are found to have no descriptive impact on apply-issue durations. However, the data suggest that SolSmart-designated AHJs process permits more quickly during the issue-pass phase (Fig. 5). In particular, the median issue-pass duration is about 7 days shorter in gold-designated AHJs than in undesignated AHJs.

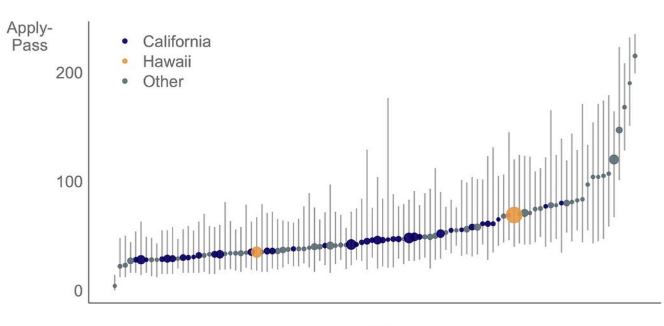

Fig. 4. AHJ-level median and inter-quartile ranges for apply-pass durations. Point sizes represent sample size. Limited to the 100 AHJs with the most records in the data and sorted along the x-axis based on median apply-pass duration.

Our second additional data source is a set of AHJ policy databases compiled by several large-scale PV installers. The information in these databases represents AHJ permitting policies as observed and recorded by installers who operate in those AHJs. As a result, there are three caveats to these installer-generated databases. First, the information is based on installer observations that may or may not accurately reflect AHJ permitting policies. Second, the geographic coverage of the databases is limited to the AHJs where the installers operate. Third, the information represents installer observations at a specific point in time, generally in 2018–2019, such that the AHJ policies recorded in these databases may or may not reflect the prevailing AHJ policies at the time when BuildZoom records were generated. For this reason, we restrict this particular analysis to 17,173 records with an application date in 2017 or later in 123 AHJs that were matched with the installer data.

Notwithstanding these caveats, the installer data provide more nuanced insights into differences in AHJ-level permitting policies and their potential effects on permit durations. The installer data suggest that:

- *Durations are shorter in AHJs that involve fewer departments in approvals.* The installer data suggest that 4% of AHJs in the data do not require permit approvals from any permitting departments after the permit has been issued, 55% require approvals from 1 department, 31% require approvals from 2 departments, and 10% require approvals from 3 departments. The data indicate that durations increase with the number of required approvals (Fig. 6, left). The median apply-pass duration increases from 30 days in AHJs that do not require any approvals to 47 days in AHJs that require 2 approvals.
- *Apply-issue durations are shorter in AHJs with online permitting processes, outside California.* The installer data suggest that about 37% of AHJs in the data allow or require online permit applications. Outside California, the median apply-issue duration is 0 days and the inter-quartile range is 3 days in AHJs that allow online permitting compared to a median of 1 day and inter-quartile range of 9 days in

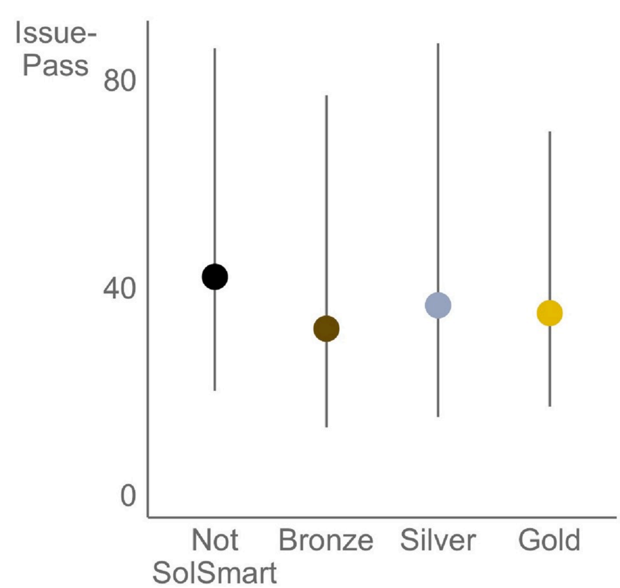

Fig. 5. Median issue-pass durations with interquartile ranges by SolSmart designation.

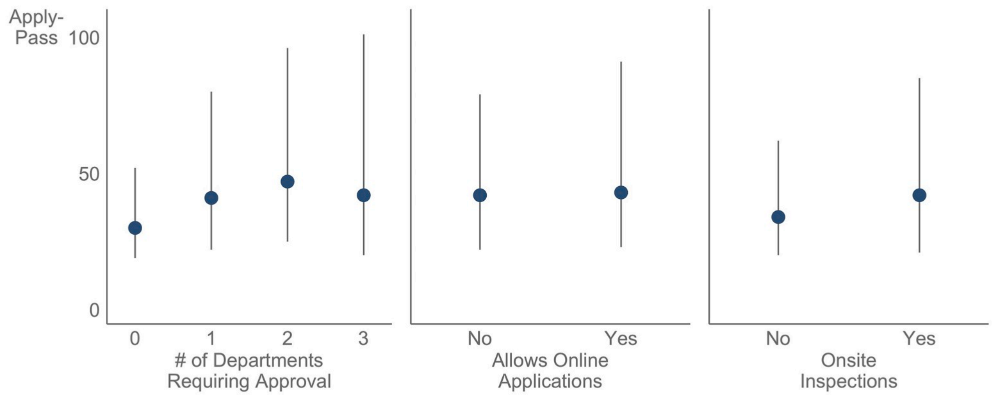

Fig. 6. Apply-pass duration distributions by: left – number of departments requiring an approval; center – whether AHJs allow online applications; right – whether AHJs require onsite inspections.

AHJs that do not. However, in California, apply-issue durations are actually 2 days longer at the median in AHJs that allow online permitting. As a result, median apply-pass durations in the data are 1 day longer in AHJs that allow online permitting (Fig. 6, center).

- *Durations are longer in AHJs that require onsite inspections.* The installer data suggest that about 80% of AHJs in the data require an onsite system inspection for permit approval. Median apply-pass durations are 8 days longer and apply-pass interquartile ranges are 22 days longer in AHJs that require onsite inspections than in AHJs that do not (Fig. 6, right). This result suggests that policies that obviate the need for onsite inspections, such as through virtual inspections, could significantly reduce permit durations and increase duration certainty.

4.2. Durations across installers

PV installers play a key role in the PV permitting process, and differences in installer strategies may affect permit durations. PV installers may play a particularly important role during the issue-pass phase in at least three ways. First, differences in installer scheduling and installation crew availability could drive variations in delays from permit issuance to installation. Second, some installers may navigate inspections more efficiently than others, or may navigate inspections more efficiently in certain AHJs than in others. For instance, installers may be more likely to pass inspections with local inspectors with whom they have experience. Third, installers may have different strategies around when to submit the permit application. For instance, some installers may choose to submit permit applications well in advance of the scheduled installation date, while others may choose to submit the application only when they are ready to install the system. All else equal, records associated with early permit application submitters will be associated with longer issue-pass durations, even if the overall installation timeline is the same.

Most PV installers are local companies, operating in one or a small number of AHJs. As a result, some observed variation in permit durations across installers may actually be attributable to variation in durations in the different markets in which installers operate. To isolate installer-level variation, we analyze installer-level permit durations within three illustrative AHJs with large numbers of records in the data: Boulder, CO (N = 3334), Honolulu, HI (N = 42,107), and Los Angeles, CA (N = 5085).[7] We identified the 10 installers with the largest number of records in each of the three AHJs. Apply-issue durations vary across these installers within each AHJ (Fig. 7). In Los Angeles, the median installer-level apply-issue duration varies from 0.5 days to 12 days. Issue-pass durations vary more significantly across installers within the AHJs (Fig. 8). In each case, installer-level median issue-pass durations vary by at least 39 days from the shortest-duration installer to the longest-duration installer. These results suggest that permit durations vary across installers even when those installers are—in theory—subject to the same permitting requirements.[8]

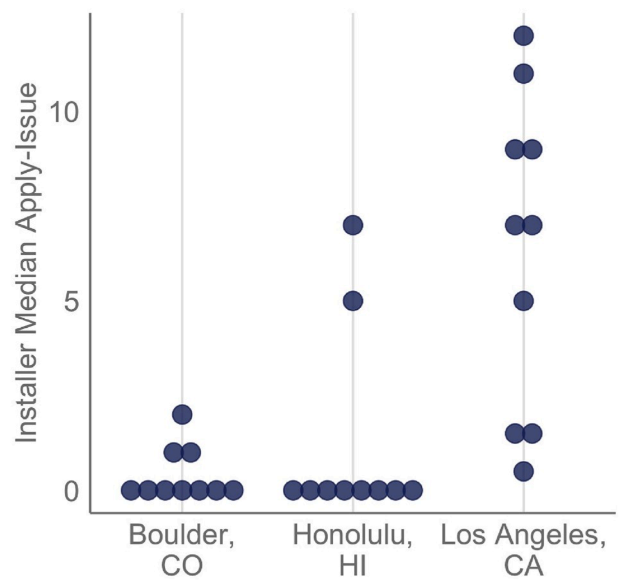

Fig. 7. Installer-level median apply-issue durations in three illustrative AHJs. Based on 10 installers with the most records in each AHJ.

The prior results suggest that permit durations vary across installers within AHJs. This result could be explained in two ways: 1) Some installers are consistently associated with shorter/longer durations regardless of the AHJ; or 2) Installers navigate different AHJ permitting processes in different ways. The data support both explanations, but particularly the former. Fig. 9 depicts installer-level variation across 20 California AHJs for the group of 5 installers with the most records in those AHJs. In this example, some installers are consistently associated with longer issue-pass durations (e.g., the upward red triangles) than other installers (e.g., the downward blue triangles). This result suggests that variation from installer-level factors can—to some extent—dominate variation from AHJ-level factors. However, the figure also

[7] Sample sizes based on number of records with valid installer names.

[8] Requirements within each AHJ may have changed over time, such that installers with more records early on were subject to different requirements than installers with more records later in the data. However, similar installer-level variation remains evident within each AHJ for specific years.

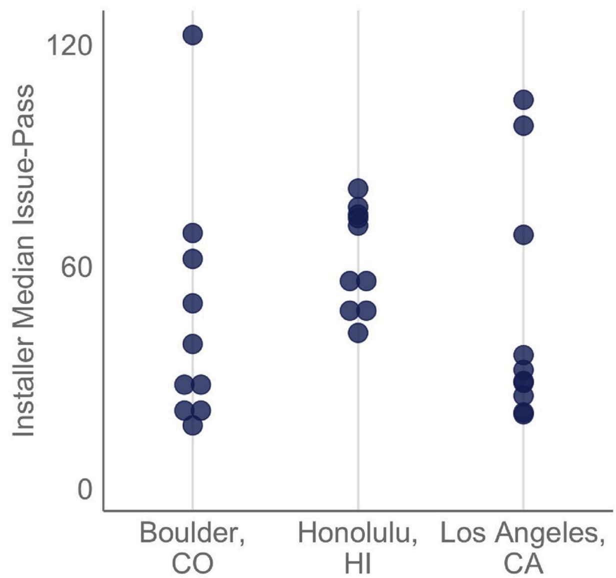

Fig. 8. Installer-level median issue-pass durations in three illustrative AHJs. Based on 10 installers with the most records in each AHJ.

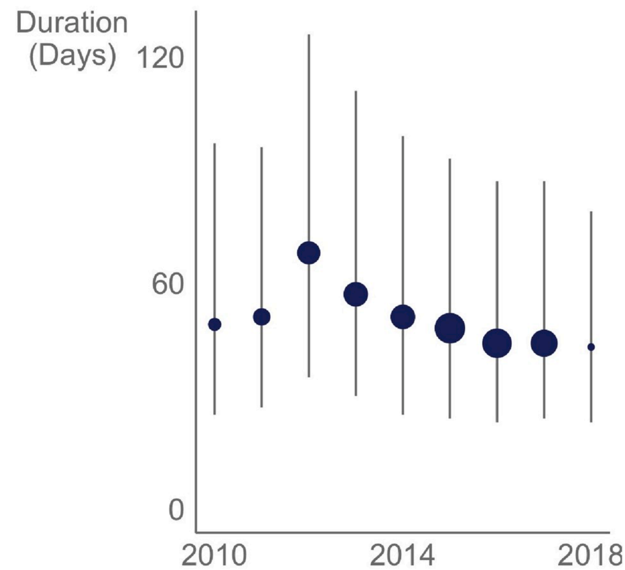

Fig. 10. Apply-pass median and inter-quartile ranges by year. Point sizes represent sample size.

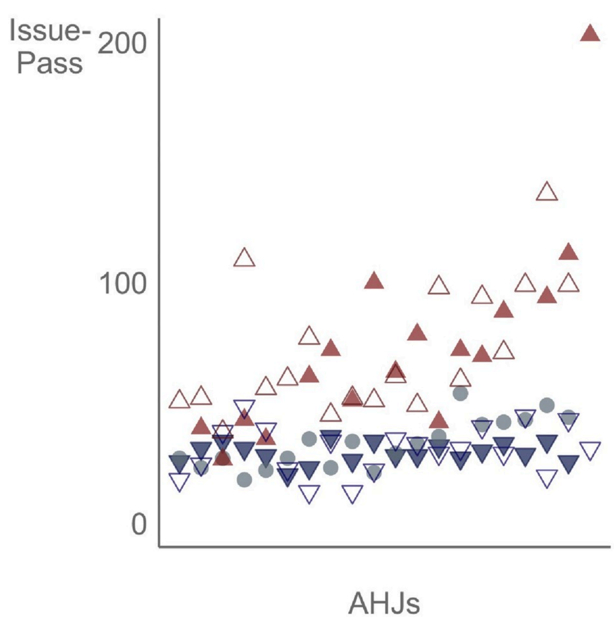

Fig. 9. Installer-level median issue-pass durations by AHJ. Each shape/color represents a different installer (names not included for proprietary data reasons). Based on 20 AHJs in California with the most records in the data and the 5 installers with the most records in those AHJs. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

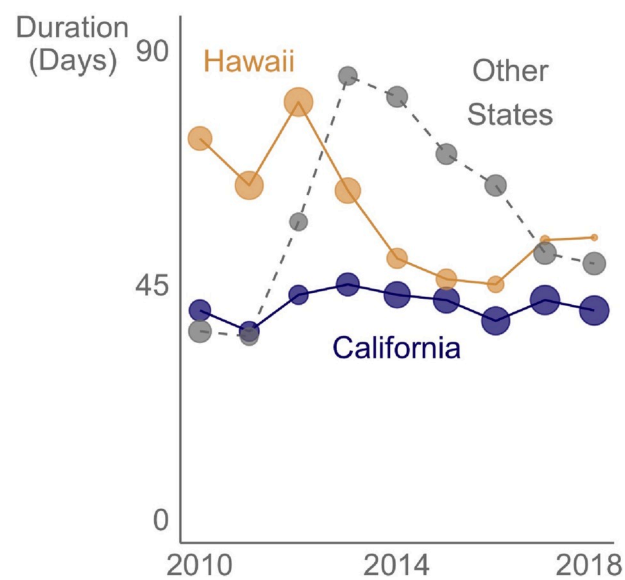

Fig. 11. Median apply-pass durations in California, Hawaii, and other states over time. Point sizes represent sample size.

supports the second explanation. The installers represented by red triangles appear to navigate the permitting processes in different ways across the AHJs, while the remaining installers exhibit relatively constant issue-pass durations across the AHJs.

4.3. Durations over time

Permit durations within the BuildZoom dataset steadily declined from a median of 68 days in 2012 to 43 days in 2018 (Fig. 10). Additionally, the distributions of durations have narrowed over time, with the 75th percentile duration falling from 126 days in 2012 to 79 days in 2018. This result is primarily attributable to two trends driven by Hawaii (Fig. 11). First, apply-pass durations declined in Hawaii from a median of 80 days in 2012 to 54 days in 2018, due primarily to declining durations in Honolulu. Second, Hawaii's share of the data declined over the same time period, from about 62% of the data in 2012 to just 2% in 2018. Given that Hawaii is a relatively long-duration state, Hawaii's declining share of the data has shifted the statistical center of the data toward the lower durations of other states, particularly California. The first trend represents a true reduction in permit durations, while the second trend is simply due to changes in the underlying composition of the data. In California, median apply-pass durations fell just 3 days over the same timeframe, from 43 days in 2012 to 40 days in 2018. Permit durations in the remaining states declined from 85 days in 2013 to 49 days in 2018, largely due to duration reductions in Florida (169 days–55 days) and New York (162 days–91 days).

The temporal trends depicted in Fig. 11 are consistent with the finding from Salmon et al. (2014) that permit durations in California stabilized after a period of initial reductions due to the state's permit streamlining policies (see Section 4.1). Similar trends are evident in Hawaii and other states, where permit durations appear to fall from 2012 to 2016 but then stabilize around the same median levels observed in California. As noted in Section 2, Salmon et al. (2014) posit two explanations for the stabilization of permit durations: 1) Increasing application volumes offset any permit duration reductions achieved through streamlining policies; and 2) AHJs "learn" over time to process permits more efficiently, but longer durations in inexperienced AHJs can still weigh down overall permit durations. Descriptive analyses of these hypotheses yielded inconclusive results, in part because it is difficult to isolate the effects of streamlining policies, application volumes, and AHJ learning on permit durations. Another hypothesis is that AHJ policies can only reduce permit durations by so much. After the implementation of best-practice AHJ policies, further reductions may increasingly rely on other factors, such as installation timelines. We return to these hypotheses in Section 5.

5. Duration analysis model

The duration analysis model results counter the learning and volume hypotheses during the apply-issue phase, as indicated by the positive coefficient on the AHJ experience variable and the insignificant negative coefficient on volume in the apply-issue model (Table 3). However, the model supports these hypotheses in the issue-pass phase, as indicated by the negative coefficient on AHJ experience and the positive—though still insignificant—coefficient on volume in the issue-pass model. One potential explanation for the inverse effect of application volumes on apply-issue durations is that AHJs expedite application reviews when they face large application volumes in order to avoid large application backlogs.[9] The issue-pass model suggests that issue-pass durations decline by about 2% for every additional 1000 applications of cumulative experience, consistent with the learning-by-doing hypothesis. Because issue-pass durations contribute more to overall durations than do apply-issue durations, the apply-pass model likewise suggests that AHJ experience results in shorter apply-pass durations. The positive coefficient on the volume variable indicates that these gains from AHJ experience may be partially offset in the issue-pass phase by increasing permit application volumes. The negative coefficient on the installer experience variable for the apply-pass model provides some evidence of installer learning during the permit application process.

The apply-issue model suggests that apply-issue durations are about 25% shorter in SolSmart-designated AHJs than in undesignated AHJs.[10] That result suggests that AHJ best-practice policies can reduce permit application review times, though the model suggests that SolSmart designation has no impact on issue-pass durations. Further, the apply-issue model suggests that apply-issue durations are slightly longer in AHJs with older housing stocks (housing age), suggesting that permit applications for older homes with older roofs and electrical systems are subject to additional scrutiny during the permit application review period. The data suggest that older electrical systems, in particular, may draw additional permitting scrutiny: an electrical permit was required for about 53% of records in AHJs where more than 90% of homes were built before 2000 compared to about 24% of records in AHJs where fewer than half of homes were built before 2000. At the same time, the model suggests that issue-pass durations are *shorter* in AHJs with older housing stocks. There may be some confounding factor to explain this outcome, but one hypothesis is that contractors are more familiar with roofing structures and electrical systems in older homes, which may save time and effort during the installation and inspection processes. Finally, the issue-pass model suggests that records with roofing permits are associated with shorter issue-pass durations than records without such permits, consistent with the descriptive results. This result is particularly striking in that it counters expectations: one would assume that records with roofing permits represent more complex jobs (e.g., roof replacement) and would therefore be associated with longer rather than shorter durations. One potential explanation is that PV systems installed on new rooftops are less likely to experience inspection delays due to structural issues associated with the roof.

The fixed effect results provide further evidence that nuanced AHJ- and installer-level factors can explain variation in permit durations. 193 of the 275 AHJ-level apply-pass fixed effects are statistically significant, while 15 of the 18 installer-level apply-pass fixed effects are statistically significant. The quarter fixed effects are mostly insignificant, indicating that temporal trends in permit durations can be largely explained by other time-varying factors such as AHJ experience and application volumes.

Table 3
Duration analysis model results.

	Y = log (apply-issue)	Y = log (issue-pass)	Y = log (apply-pass)
AHJ experience (x1000)	0.04*	−0.02*	−0.02*
	(4.1)	(6.9)	(7.2)
Volume (x1000)	−0.00	0.02	0.007
	(0.01)	(1.7)	(0.6)
Installer experience (x100)	−0.02*	0.003	0.001
	(3.9)	(0.8)	(0.3)
SolSmart	−0.29*	0.04	−0.008
	(2.7)	(0.4)	(0.1)
Electrical	−0.06	−0.02	−0.01
	(0.5)	(0.6)	(0.3)
Roofing	−0.02	−0.09*	−0.06
	(0.1)	(2.2)	(1.7)
Other permits	0.13	−0.04	−0.02
	(1.3)	(1.0)	(0.4)
Housing age	0.002*	−0.002	−0.002*
	(2.0)	(1.4)	(2.4)
AHJ FE	X	X	X
Installer FE	X	X	X
Quarter FE	X	X	X

Robust z-statistics in parentheses; $^{*}p < 0.05$.

6. Conclusion and policy implications

In this article, we build on previous descriptions of PV adoption processes and durations (Stanfield et al., 2013; Salmon et al., 2014; Ardani et al., 2015; Sinitskaya et al., 2019) through a data-driven analysis of trends in durations and the factors that explain differences in durations across AHJs. We build on the existing literature with data-driven insights into PV permit durations, key trends across space and time, and the factors that drive permit durations (Table 4).

The results suggest that permit streamlining policies and AHJ experience have reduced PV permit durations over time. Nonetheless, permit durations have appeared to stabilize in recent years in most AHJs and have remained stable in California for nearly a decade. Whether further reductions in permit durations are desirable is a normative question beyond the scope of this article. However, the data show that some AHJs and installers are able to navigate the PV permitting processes faster than others, suggesting that further reductions in permit durations are possible. For instance, in 2017, the median apply-pass duration was 44 days, yet 10% of AHJs had a median apply-pass duration of 27 days or less, and 10% of installers had a median apply-pass duration of 19 days

[9] Also, as noted in Section 2, we have less confidence in the apply-issue estimates than in the issue-pass estimates. It is possible that underlying biases in the data are obscuring the effects of learning and application volumes.

[10] $-0.29^{e} = 0.748$, i.e., a roughly 25% reduction.

Table 4
Summary of key findings in the context of previous research.

Research Question	Previous Research	Findings
What is the duration of a typical PV permit?	No previous work, to our knowledge, has comprehensively estimated durations for the full permitting process.	At the median, a typical PV installation takes about 50 days from permit application to pass inspection.
How do these durations vary?	Permit application review times can vary from 1.5 to 30 days (Stanfield et al., 2013).	Permit durations vary from 26 to 97 days at the 25th and 75th percentiles.
What are the key trends in permit durations across space and time?	Permit application review periods vary significantly across AHJs (Stanfield et al., 2013). PV permit durations declined in California from 2007 to 2009 but stabilized from 2009 to 2013 (Salmon et al., 2014).	Permit durations vary significantly across states and AHJs. Durations declined in some key markets (e.g., Hawaii) but remained relatively stable in others (e.g., California).
What factors explain variations in permit durations?	Installers identify permit applications and inspections as key "pain points" in the permitting process (Sinitskaya et al., 2019).	The data suggest that permit durations decline as AHJs and installers accumulate more PV permitting experience. There is also evidence that AHJ policies to expedite PV permitting can shorten permit durations.

or less.[11] Put another way, considering the AHJ- and installer-level 10th percentiles as reasonable measures of aspirational yet attainable low-bound permit durations, AHJ- and installer-level efforts could reduce most permit durations by around 17–25 days. Further reductions in permit durations may require additional state, AHJ, and installer efforts to streamline permitting and installation processes.

The results give additional weight to arguments that inconsistent PV permitting requirements pose a barrier to PV deployment (Stanfield et al., 2013; Argetsinger and Inskeep, 2017), providing further rationale for permitting standardization at the state or national level. However, the data show that permit durations vary as significantly *within* as across AHJs (see Fig. 4). We have presented several analyses to explore this within-AHJ variation, with one clear driver being differences across installers. Regardless of the explanation for this variation, one implication is clear: PV customers face highly uncertain timelines during the PV permitting and installation process. In any given AHJ, a typical customer faces a window of more than two months for the expected timeline between permit application and a passed inspection (see Section 3.1). The magnitude of the variability in durations is remarkable unto itself, particularly considering that most PV installations only require one or two days of onsite labor. Uncertain permitting and installation timelines may deter risk-averse customers from entering the permitting process. These results suggest that at least some policy focus may need to shift from reducing average permit durations to reducing the variation in those durations.

Finally, and related, while the PV permitting literature has generally focused on the role of AHJs, the data suggest that installers play an important role in determining PV permit durations. Even highly streamlined PV permitting policies may have little impact on durations if installers implement strategies that result in long lags between permit issuance, installation, and inspection.

We conclude by suggesting several areas for future research building on these results. First, future research could explore the effects of AHJ-level policies more directly by compiling a database of AHJ-level PV permitting policies over time. Second, and related, future research could explore what explains differences in AHJ-level permitting policies through studying factors such as AHJ-level resources and culture. Third, future research could explore the potentially detrimental effects of PV permit duration uncertainty on PV deployment. One possibility is that lengthy and uncertain durations can generate negative peer effects when neighbors share their negative adoption experiences and deter other neighbors from adoption. Lengthy and uncertain durations may also increase the chances that a customer cancels their contract before the system is installed. Fourth, future research could further explore the effects of demographic and other factors that appear to affect PV permit durations, such as housing age. Last, future research could explore potential policy levers that could optimize the role of installers in the PV permitting process, such as policies that discourage installers from submitting permit applications long before the expected installation date.

[11] Statistics are based on AHJs and installers with at least 10 records in 2017.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Eric O'Shaughnessy: Conceptualization, Methodology, Formal analysis, Data curation, Writing - original draft, Visualization. **Galen Barbose:** Validation, Investigation, Writing - review & editing. **Ryan Wiser:** Writing - review & editing, Supervision, Project administration, Funding acquisition.

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