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September 12, 2024

Via E-Filing

Ms. Lisa Felice
Executive Secretary
Michigan Public Service Commission
7109 West Saginaw Highway
Lansing, MI 48917

RE: MPSC Case No. U-21534

Dear Ms. Felice:

Please find enclosed the Official Exhibits DAO-214 to DAO-224 sponsored by Yunus Kinkhabwala (Part 6 of 10) on Behalf of Soulardarity and We Want Green, Too, along with proof of service for electronic filing in the above-referenced matter. Please do not hesitate to contact me with any questions or comments.

Sincerely,

A handwritten signature in black ink, appearing to read "Mark N. Templeton".

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xc: Parties to Case No. U-21534

Composition, Emissions, and Air Quality Impacts of Hazardous Air Pollutants in Unburned Natural Gas from Residential Stoves in California

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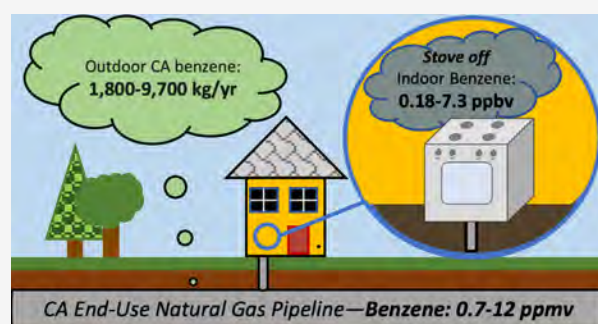
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ABSTRACT: The presence of hazardous air pollutants (HAPs) entrained in end-use natural gas (NG) is an understudied source of human health risks. We performed trace gas analyses on 185 unburned NG samples collected from 159 unique residential NG stoves across seven geographic regions in California. Our analyses commonly detected 12 HAPs with significant variability across region and gas utility. Mean regional benzene, toluene, ethylbenzene, and total xylenes (BTEX) concentrations in end-use NG ranged from 1.6–25 ppmv—benzene alone was detected in 99% of samples, and mean concentrations ranged from 0.7–12 ppmv (max: 66 ppmv). By applying previously reported NG and methane emission rates throughout California's transmission, storage, and distribution systems, we estimated statewide benzene emissions of 4,200 (95% CI: 1,800–9,700) kg yr⁻¹ that are currently not included in any statewide inventories—equal to the annual benzene emissions from nearly 60,000 light-duty gasoline vehicles. Additionally, we found that NG leakage from stoves and ovens while not in use can result in indoor benzene concentrations that can exceed the California Office of Environmental Health Hazard Assessment 8-h Reference Exposure Level of 0.94 ppbv—benzene concentrations comparable to environmental tobacco smoke. This study supports the need to further improve our understanding of leaked downstream NG as a source of health risk.

KEYWORDS: BTEX, benzene, downstream, fossil fuels, natural gas leak, cooking, hazardous air pollutants, indoor air quality, regional BTEX inventories



INTRODUCTION

In 2021, the United States consumed approximately 30.2 trillion cubic feet of processed natural gas (NG), comprising 32% of total U.S. energy consumption, of which 15% was consumed by an estimated 74.6 million residential households.^{1–3} Non-methane volatile organic compounds (NMVOCs) are naturally present in unprocessed NG;^{4–9} however, very little data exists on the chemical composition and concentrations of hazardous air pollutants (HAPs) in processed NG at the point of end use.¹⁰ Moreover, the indoor air quality impacts from fugitive NMVOC or HAP emissions associated with known NG leakage or incomplete combustion pathways are understudied, in part, due to a lack of chemical characterization of downstream NG.¹¹

While NG transmission pipelines have some NMVOC restrictions to prevent operational failures (see Federal Register Vol 71 No 120), there are no corresponding limits on HAPs in transmission pipeline gas in the United States.^{12–16} Many NMVOCs are hazardous to human health and therefore have been deemed HAPs under the U.S. Clean

Air Act, which is further exemplified by various state, federal, and international health-based guidelines for exposure to these compounds.^{17,18} For example, NMVOCs contribute to the formation of ozone, a constituent of photochemical smog, and fine particulate matter (PM_{2.5}).^{19–21} Benzene is a known human carcinogen that increases the risks of developing leukemia.²² One study detected benzene, toluene, ethylbenzene, and xylenes (BTEX) and other health-damaging NMVOCs in downstream NG;²³ however, these data were not quantitative and only included two samples. Recently, Michanowicz et al.²⁴ found extensive NMVOCs in distribution NG in Massachusetts; however, measurements were confined to a region that is geographically far from hydrocarbon

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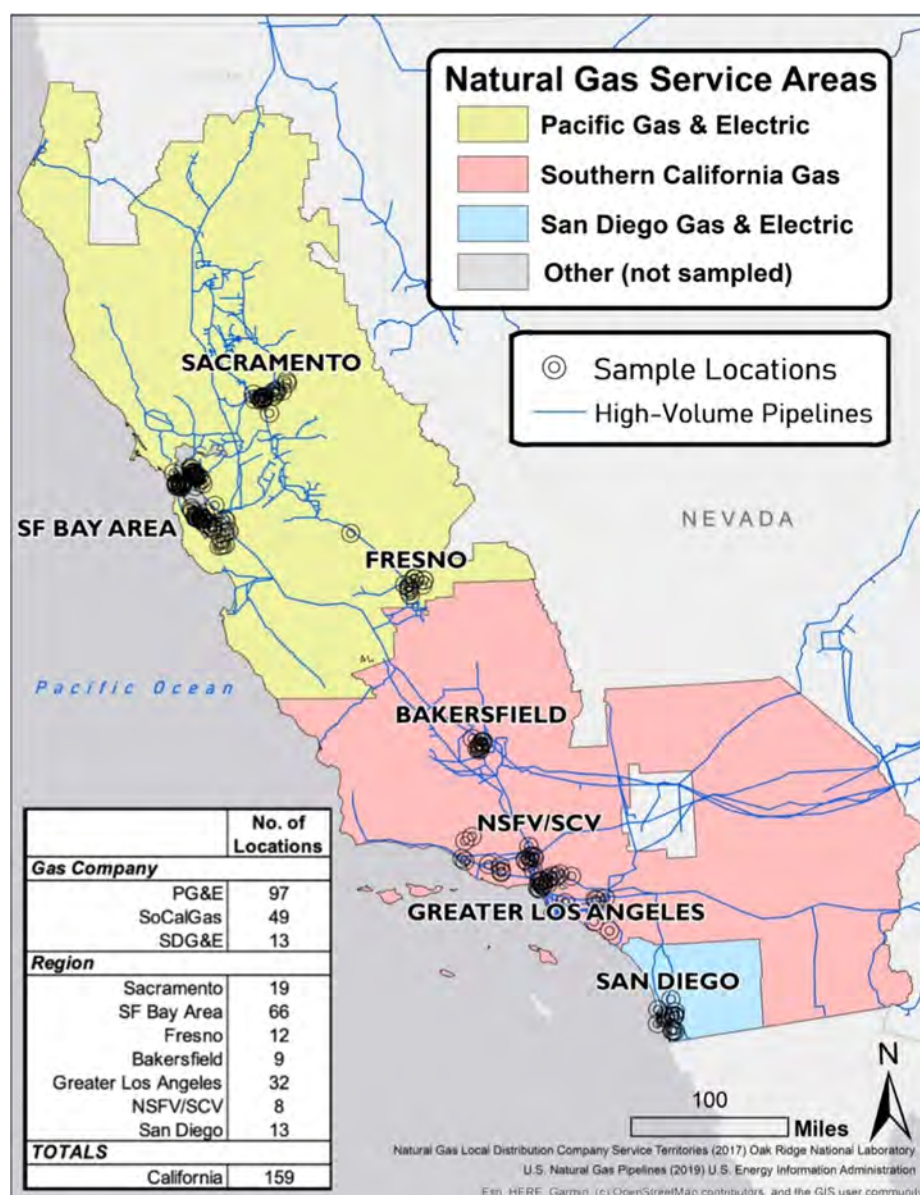


Figure 1. Spatial distribution of the 159 households sampled in California. The points show the location of each of the samples. The shading shows gas utility service territories in each region, and the blue lines represent high-volume pipelines traversing California and neighboring states. Measurements were taken in the following gas companies' territories: Pacific Gas and Electric (PG&E)—yellow; Southern California Gas Company (SoCalGas)—red; and San Diego Gas & Electric (SDG&E)—blue. Samples were grouped into one of 7 different regions which we used throughout this study: San Francisco (SF) Bay Area, Sacramento, Fresno, Bakersfield, North San Fernando/Santa Clarita Valleys (NSFV/SCV), Greater Los Angeles (excluding NSFV/SCV), and San Diego.

production or underground NG storage in depleted oil reservoirs—two features present throughout California that may impact NMVOC concentrations in NG. There are also limited publicly available NMVOC composition data for the transmission and storage sector,²⁵ and it is unclear the degree to which these trace gases persist in the end-use gas distribution system.

Residential NG saturation in California is the second highest in the United States, with 88% of all households (11.5 million in total) having NG service in 2020. Typically, 70% of these homes cook with an NG-powered stove or oven, representing the highest percentage of gas stove users in the country.¹ Driven in part by concerns regarding the climate-forcing nature

of methane, multiple studies in California have quantified NG emissions from buildings and appliances. Fischer et al.²⁶ measured NG appliance leakage in 75 homes in California and found that chronic, low-level leaks can persist undetected directly in residential homes and that 15% of total NG methane emissions in California could be attributed to fugitive post-meter (i.e., in-home) emissions. Lebel et al.^{27,28} observed that at least 75% of total emissions from gas stoves and storage water heaters originate while they are off.^{27,28} These leakage profiles, in combination with uncertainties related to the effectiveness of NG odorants as exposure deterrents,^{24,29–34} support the need for further study of potential risks of exposure

to health-damaging compounds contained in end-use NG in California.

In this study, we adopted canister collection methods with gas chromatography–mass spectrometry (GC–MS) NMVOC analysis from Michanowicz et al.²⁴ to determine the chemical composition of unburned NG from downstream NG supply in seven distinct geographic locations in the state of California.²⁴ Our goals for studying the gas stream at the point of end use were twofold: (1) To understand the contribution of NMVOCs to urban air quality associated with leakage throughout the downstream NG supply chain, and (2) To understand potential indoor exposures from known leakage pathways. To begin to address goal 1, we combined these NG composition data with existing California-specific NG leakage data to estimate unaccounted-for BTEX emissions for the entire state and for certain individual source types within the downstream infrastructure. To address goal 2, we estimated indoor residential ambient benzene concentrations attributable to published rates of NG leakage from household gas stoves and ovens while off across various scenarios.^{35,36} We compared these indoor air concentrations of benzene to the California Environmental Protection Agency Office of Environmental Health Hazard Assessment (OEHHA) benzene Reference Exposure Level (REL) to evaluate health risks from this understudied environmental exposure.³⁷

METHODS

Data Collection. We collected 185 unburned NG samples from 159 unique residential NG stoves in California. We used passivated 1 L SUMMA or Silonite-lined Entech canisters with Teflon tubing to form a direct in-line connection with a single-stove burner NG outlet orifice. NG samples were analyzed by two labs based in California with Environmental Laboratory Accreditation Program (ELAP) certification. We used two labs to accommodate canister availability (Lab 1: $n = 54$; Lab 2: $n = 131$).

NMVOCs for all samples were analyzed using U.S. Environmental Protection Agency Method TO-15, which calls for sample separation and analysis by gas chromatography and mass spectroscopy.³⁸ Samples were analyzed by the lab within 30 days of collection—the maximum hold time specified by the TO-15 method during which concentrations are considered stable. The TO-15 analyte list included 69 compounds from Lab 1 and 63 compounds from Lab 2. We quantified a total of 76 unique compounds using TO-15 across the two laboratories, including 56 compounds analyzed by both labs (see Table S1 for a complete list). Each sample was also tested using Method ASTM D1946 to quantify methane and ethane content in unburned NG as well as elemental nitrogen and oxygen for all but 27 samples.³⁹ These data were used for quality control to ensure pure NG sample collection and to verify minimal ambient air intrusion during sampling.

We collected samples using a similar methodology as described in detail in Michanowicz et al.²⁴ and briefly summarized here. First, we removed gas stove flame spreader plates and metal grates to expose the NG outlet orifice. We then applied Teflon-lined tubing of 1/4" inner diameter to tightly enclose the NG outlet orifice, bypassing any ignition sources and minimizing the potential for NG leakage or ambient air entrainment. We then turned the gas flow knob between medium and high for the entirety of the sampling event. After flushing the hosing, we immediately connected it to the sampling canister provided by the lab via a cone washer

and screw nut or quick release connection. We filled canisters until the vacuum on the canister was between -5 and 0 in Hg, taking approximately 20–30 s. For safety, we deployed a Bascom Turner Gas Rover or similar device near the stove to ensure the concentration of leaked NG did not approach the lower explosive limit of methane (5% v/v gas), and we turned on range hoods when present during and after the sampling process to reduce indoor air concentrations of NG.

We intentionally designed this measurement campaign to sample NG in major urban areas serviced by the three main NG utilities in California: Pacific Gas and Electric (PG&E), Southern California Gas Company (SoCalGas), and San Diego Gas & Electric (SDG&E). In all, we collected samples from 16 counties across California from these three utilities and grouped samples into seven regions we defined: the San Francisco Bay Area (San Francisco, San Jose, Oakland, and nearby cities); Sacramento and Fresno [PG&E]; Greater Los Angeles; the North San Fernando and Santa Clarita Valleys; and Bakersfield [SoCalGas]; and San Diego [SDG&E]. We collected samples between February and September 2021 (Figures 1 and S2).

Quality Control and Data Analysis. Data from our 185 samples are reported as pure gas mole fractions (concentrations) in parts per billion by volume (ppbv). Lab 1 reported directly in ppbv, while Lab 2 required conversion from mass concentrations to volumetric concentrations (ppbv) using the molecular weight of the compound and assuming normal temperature (298 K) and pressure (101.3 kPa). For values below the lab's internal limit of detection, we took a conservative approach and assigned these data as zero.⁴⁰

We took several quality control measurements throughout the study, in addition to blanks and other quality checks performed by the labs. First, to compare our NG samples to background air collected by the same method, we collected one field blank by attaching the hosing to the stove and not turning the gas on and one ambient air blank by opening the can in the kitchen space with no hosing attached, both of which did not detect target analytes. Second, we used both methane and elemental nitrogen (N_2) as source signature tracers—methane as proxy for NG, and nitrogen as proxy for ambient air. Using these fixed gas measurements, we conducted a k-means cluster analysis to exclude samples that entrained a substantial amount of ambient air. Based on our analysis, we identified two k-clusters and excluded the cluster with the lowest methane and highest nitrogen values (Figure S1). To control for samples that did not have a paired nitrogen, nine samples were additionally excluded that had a methane measurement within the range of the excluded k-cluster. The mean of benzene and total BTEX of the excluded samples were less than the mean of the included samples; this is unsurprising, given the assumed dilution effect from ambient air intrusion (Figure S1).

We also collected a series of samples to quantify variability across our study. These included duplicate samples (collected consecutively at a single location) analyzed by different labs; duplicate samples analyzed by the same lab; and repeated samples that were collected in the same households several months apart (Note S1). In our analysis, duplicates collected on the same day were treated as replicate samples; therefore, we selected only the first of the two samples to be used in our analyses. For the times we collected repeat samples in different months, we treated them as independent samples for regional

and statewide means as household-level factors should not influence gas composition.

Regional and Statewide Emissions Estimates. To evaluate the contribution of downstream NG emissions to regional and statewide benzene and BTEX budgets, we used methane emission estimates from previous studies of the downstream NG sector in California to scale bootstrapped regional and statewide mean concentrations of benzene and total BTEX measured in our study.^{26,28,41–44} Emissions rates of benzene and total BTEX were calculated using the following equation adapted from Marrero et al.⁶

$$E_{\text{NMVOC}} = E_{\text{methane}} \times C_{\text{NMVOC}} \left(\frac{MW_{\text{NMVOC}}}{MW_{\text{methane}}} \right) \quad (1)$$

where E_{NMVOC} represents the NMVOC mass flow rate (kg yr^{-1}); E_{methane} represents the methane mass flow rate (Gg yr^{-1}) derived from existing literature;^{26,28,41–44} C_{NMVOC} represents the state or regional concentration of NMVOCs in the pipeline NG (ppmv); and MW_{NMVOC} and MW_{methane} represent the molecular weights of the NMVOC and methane, respectively (g mol^{-1}). This relationship assumes that the concentration of methane in pipeline NG is 100%, and as such, we are slightly underestimating total NMVOC emissions. Scaled benzene emissions (E_{NMVOC}) assume a benzene-to-methane ratio that is conserved throughout the distribution pipeline network and likely underestimates NMVOC emissions using methane flux rather than NG flux. The emissions estimates also assume no differential mechanisms of transport and fate between methane and benzene emissions (e.g., soil adsorption)—a limitation of this methodology.

Regional and distribution pipeline methane emissions were taken from available data sources in the literature to scale our NMVOC emissions. NMVOC emissions for the North San Fernando and Santa Clarita Valleys specifically were estimated using distribution pipeline NG emissions from SoCalGas for zip codes in this region (Figure S4) and NMVOC measurements from our samples in the North San Fernando and Santa Clarita Valleys.

Indoor Air Quality Modeling. To better understand the potential indoor air quality implications of benzene content in end-use NG leaked from gas stoves while turned off, we modeled ambient benzene concentrations in the kitchen and compared the results to California's Reference Exposure Levels (REL). We modeled 140 scenarios that varied unburned NG leakage rates (median: 24 mg hr^{-1} and 95th percentile: 282 mg hr^{-1} , from Lebel et al.²⁸), benzene concentrations in unburned gas (median and 95th percentiles calculated from this study), and household parameters (Table S2). We used CONTAM—a multizone, whole-building model developed by the National Institute of Standards and Technology—that can be used to estimate contaminant concentrations in the indoor environment using information about the structure, ventilation, airflow, and contaminants.^{35,36,45}

Here, as an introductory assessment of the impact of leaked NG on indoor air quality, we conservatively focused only on leakage from a single gas stove/oven while off (steady-state off) and for only one pollutant: benzene. This modeling approach almost certainly underestimates the true quantity of behind-the-meter NG emissions which also may include leaks from other gas appliances and emissions of natural gas when the stove/oven is on.

We calculated benzene steady-state-off leakage rates from stoves using the following relationship

$$V_{\text{benzene}} = V_{\text{methane}} \times C_{\text{benzene}} \quad (2)$$

where V_{benzene} represents the volumetric emissions of benzene from the leaking stove (nL hr^{-1}); V_{methane} represents the volumetric methane emissions rate from the leaking stove (mL hr^{-1}); and C_{benzene} represents the concentration of benzene in the the pipeline gas (ppmv), again assuming that the concentration of methane in pipeline NG is 100%. This enables us to directly convert the volumetric flow of methane, V_{methane} , to a volumetric flow of benzene, V_{benzene} , at a given concentration of benzene. Data on methane emission rates from leaking stoves were obtained from Lebel et al.,²⁸ who measured methane emission rates from 53 gas stoves in California using a chamber-based approach. Benzene concentrations are from this study. This relationship assumes that the emission rate of methane is equivalent to the emission rate of NG. This is a conservative assumption as distribution system NG was measured to be 90–95% methane in this study (Figure S5).

We modeled a range of household parameters and emissions rates; a complete list is in Table S2. We chose a range of households that reflects California's housing stock from the 2019 Residential Appliance Saturation Survey.⁴⁶ This included a mobile/manufactured home, an attached home, a detached single-family home, and a six-unit apartment building. Building designs were selected from the "Suite of Homes Representing the U.S. Housing Stock."^{47,48} Within each household type, we varied the air change rate, the methane emission rate, and the benzene concentration in the pipeline gas. For comparison's sake, we used only two air change rates—the buildings' natural ventilation air change rate (i.e., infiltration only) and the minimum recommended air change rate set by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE 62.2). The ASHRAE standard was achieved by parameterizing HVAC system settings to input the appropriate volume of air changes per hour. The methane emission rate and benzene concentration rate were used together to calculate the benzene emissions rate via eq 2 (Table S2). All simulations were run under steady-state airflow conditions at normal temperature (298 K) and pressure (101.3 kPa).

Across our simulations, we assumed that benzene was not reactive because the atmospheric lifetime of benzene is several days and the indoor concentrations of the hydroxyl radical ($\text{OH}^\bullet$) are similar to outdoors.^{49,50} Following previous studies, we also assumed that surface deposition would not substantially impact indoor concentrations.^{51,52} We assumed that there was no demand-controlled mechanical kitchen hood active during simulations, since our source was only fugitive emissions while off.

■ RESULTS AND DISCUSSION

Overview. We collected 185 individual samples of unburned NG from 159 unique residential stoves across seven distinct geographic locations spanning 16 counties throughout California (Figure 1). After eliminating blanks, duplicate samples, and low-methane samples that did not meet QC standards (see Materials and Methods), we retained 160 samples for analysis. Of the 76 NMVOCs analyzed, 21 unique constituents were detected in end-use NG in California (see Table S1 for a full list of pollutants). Of these, 12 carried a

HAP designation and therefore are known to cause short-term and chronic adverse health impacts.⁵³ Six NMVOCs were detected in more than 98% of NG samples, four of which are HAPs: benzene, toluene, m,p-xylene, and hexane (Figure 2).

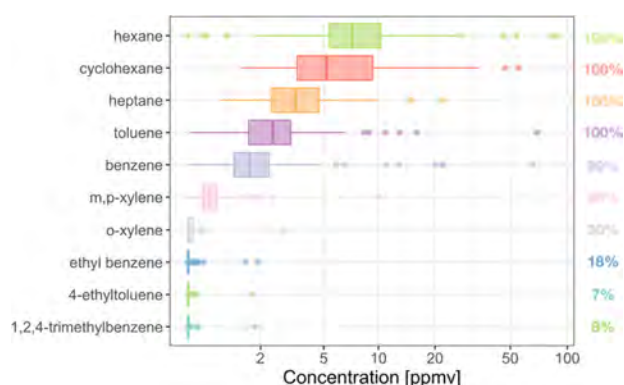


Figure 2. Summary of the top 10 non-methane volatile organic compounds (NMVOCs) detected in residential NG. Percent of values above the level of detection are listed on the right side of the figure. Note: the x-axis is a “pseudo-log” scale, which smoothly transitions to a linear scale around zero.

Median concentrations of BTEX were all within 0.1 ppmv of the means in the following regions: Greater Los Angeles, Bakersfield, Fresno, and Sacramento. This suggests regionally normal distributions of BTEX, further supported by a Kolmogorov–Smirnov test for benzene in these regions ($p > 0.05$; Figure 3 and Table S1). Notably, samples taken in the North San Fernando and Santa Clarita Valleys were not normally distributed and contained several very high benzene concentrations, including the maximum benzene concentration observed in the study—66 ppmv—which is approximately 66 times greater than the highest benzene level recorded in end-use NG in Massachusetts (max: 1.0 ppmv, mean: 0.17 ppmv).²⁴

Benzene and BTEX by Gas Company. We compared the chemical composition of NG across all three major gas utility territories in California: PG&E, SoCalGas, and SDG&E (Figures 1, 3, S2, and S3 and Table S3). Total BTEX content differed significantly by gas company (Kruskal Wallace: $\chi^2 = 25.5$, $p < 0.0001$, $n = 3$), driven in part by the significantly lower BTEX observed in the SDG&E territory compared to PG&E ($p < 0.0001$) and SoCalGas ($p < 0.0001$) territories (Wilcoxon Rank Sum Test). Samples taken in SoCalGas service areas showed the highest variability and the highest overall concentrations—over 22% of samples in SoCalGas were above the maximum benzene concentrations of 3.8 ppmv from PG&E and 3.5 ppmv from SDG&E. Differences in benzene and BTEX concentrations between SoCalGas and SDG&E were particularly unexpected, given that SDG&E is a wholesale customer of SoCalGas and purchases NG directly from SoCalGas for distribution.^{54,55} Further, both utilities reported sourcing NG from similar distribution pipeline systems and underground NG storage facilities (Note S2 and Figure S4), with the majority of gas originating from either the El Paso Pipelines sourced from basins in the Southwestern United States (i.e., the San Juan, Permian, or Anadarko Basins) or the Kern River Pipeline that sources NG from the Rocky Mountain Basin.⁵⁶ A fraction of gas comes from “California Sources,” but we did not find publicly available data that

specifies the exact source within the state (Figure S4). While BTEX concentrations did not significantly differ between SoCalGas and PG&E ($p = 0.12$), the vast majority of NG distributed by PG&E comes from Gas Transmission North-western pipeline, which sources NG from Western Canada,⁵⁶ indicating that while NG distributed by PG&E and SoCalGas is likely sourced from different basins, their C6+ content (NMVOCs with six or more carbons) was not significantly different.

Regional Benzene and BTEX Concentrations. Regional differences in BTEX concentrations (Kruskal Wallace: $\chi^2 = 46.7$, $p < 0.0001$, $n = 7$) were more pronounced than our observed differences by gas company. We observed exceptionally high NMVOCs collected in the North San Fernando and Santa Clarita Valleys (near the Aliso Canyon underground NG storage facility) and therefore analyzed these samples independently from the remainder of the samples in the Greater Los Angeles region. Notably, the 14 samples collected in this region—including 8 unique sites and 5 repeated samples in different months—exhibited some of the highest benzene and BTEX content observed throughout the entire study, with an overall mean benzene of 12 ppmv and a mean BTEX of 25 ppmv. We observed the maximum benzene concentration in the study (66 ppmv) in this region. The remaining samples collected in the Greater Los Angeles region had the most variability of the remaining regions, with a BTEX 95% CI of 7.5–24 ppmv, compared to the next highest BTEX 95% CI of 4.7–5.4 ppmv for the San Francisco Bay Area. Sacramento and Fresno had mean BTEX concentrations of 5.7 and 4.7 ppmv, respectively (Table S3). San Diego had relatively low BTEX concentrations compared to the other regions. Both Fresno and Bakersfield are located in the Central Valley but are serviced by different gas companies (PG&E and SoCalGas, respectively). This could partially account for their significantly lower BTEX content; however, these two areas represented the lowest sample counts with 12 and nine, respectively, and therefore required additional sampling to verify observed differences.

Overall, NMVOC and HAP concentrations reported in this study agree with the limited available data on NMVOC and HAP content observed in the midstream NG sector, including NG flowing through transmission pipelines, suggesting that the NG undergoes little additional processing.²⁵ For example, a study of HAPs present in transmission NG throughout the United States noted a mean benzene value of 5.9 ppmv (σ : ± 6.0 ppmv), suggesting the composition of NG in transmission pipelines may not differ substantially from that of distribution gas at the point of end use.^{25,57} Additionally, three preexisting NG composition samples associated with the Aliso Canyon underground NG storage facility (near Porter Ranch, CA) reported mol % benzene ranging from 0.0003–0.001 (3–10 ppmv),⁵⁸ which falls within the 25th–75th quartiles observed in samples in the North San Fernando and Santa Clarita Valleys from this study (1.8–20 ppmv).

While determining potential explanatory factors of trace gas variability was beyond the scope of this study, trace gas variability observed indicates that California’s NG supply chain is complex and likely reflects the multiple hydrocarbon sources both from in-state production and imports in addition to the variability of the efficacy of NG processing systems that support end-use consumption. This is further evidenced by the five samples in the North San Fernando/Santa Clarita Valleys, where we sampled during different seasons. On average, the

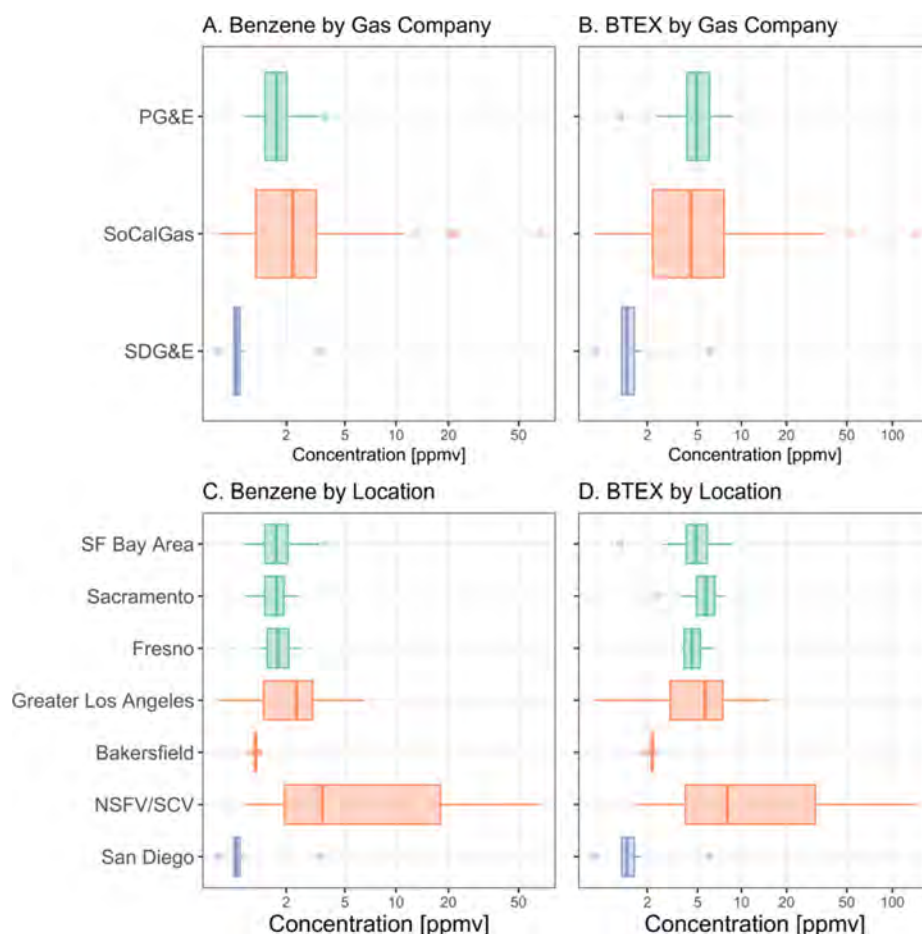


Figure 3. Concentrations of benzene and BTEX (sum of benzene, ethylbenzene, toluene, *m,p*-xylene, *o*-xylene) detected in residential NG by gas company and by location. Note that samples by location (C and D) are color-coded based on their respective gas company (A and B). Some samples collected in the North San Fernando and Santa Clarita Valleys (NSFV/SCV) had exceptionally high concentrations of BTEX in the gas; therefore, we analyzed these samples as a separate region from the remainder of the samples taken in the Greater Los Angeles region. No samples from the NSFV/SCV were included in the Greater Los Angeles region. Note: x-axis are a “pseudo-log” scale, which smoothly transitions to a linear scale around zero.

concentration of benzene in samples taken in the fall was 56% lower than samples taken in the winter/spring at the same location. Michanowicz also observed increased NMVOC concentrations during the winter heating season, suggesting that seasonal variability may be predictable and caused by source switching and/or influences from ambient temperature.²⁴

Regional and Statewide Benzene and BTEX Emission Estimates. Assuming that the NMVOC content in unburned NG observed in our study is representative of California’s transmission and distribution segments of the supply chain, we estimated annual statewide benzene and BTEX emissions using NG methane emission estimates of indoor appliances by Fischer et al.²⁶ and Lebel et al.²⁸ Our study suggests that there is an estimated 310 (95% CI: 140–980) kg benzene yr^{−1} emitted statewide from whole-house residential leaks, with an estimated 63 (95% CI: 32–150) kg benzene yr^{−1} emitted from gas stove steady-state-off leakage alone. For comparison, the 2017 NEI estimates benzene emissions from residential NG combustion (not unburned leakage) in California to be 381 kg benzene yr^{−1}.⁵⁹ Adding together benzene from combustion and our estimate of benzene from unburned leaks, our results imply that the California residential sector emits an estimated

690 kg benzene yr^{−1} from NG combustion and leakage. This suggests that the current emissions inventory underestimates benzene emissions for the residential sector by approximately 44%. This suggests that our estimate increases the existing inventory for benzene emissions from the residential sector by approximately 81%.

Using transmission and distribution methane estimates from Jeong et al.,⁴¹ the results of our study indicate that an estimated 4,200 (95% CI: 1,800–9,700) kg benzene yr^{−1} is emitted from leaks in NG distribution and transmission systems across California (Table 1).⁴¹ For context, this is a similar amount of benzene as emitted by 58,800 cars annually.^{59,60} It is also equal to nearly half of the estimated benzene emissions (~47%) from all on-road diesel light-duty vehicles in California and would rank 24th out of 49 categories of California’s benzene emissions tracked by the U.S. National Emissions Inventory (NEI).⁵⁹

Given that statewide variability in BTEX concentrations is largely driven by the Greater Los Angeles Area, we also estimated regional benzene and BTEX emissions using regional NG emission estimates by Jeong et al.,⁴² He et al.,⁴³ and SoCalGas⁴⁴ where available (Table 1). We estimated that 8.8 (95% CI: 4.5–19) kg benzene yr^{−1} is emitted from

Table 1. California Statewide and Regional Benzene and BTEX Emission Estimates Based on NG Methane Emissions from Previous Studies^{a,b,c}

study	region	sector	methane emissions (Gg/yr) (95% CI)	implied benzene emissions (kg/yr) (95% CI)	implied BTEX emissions (kg/yr) (95% CI)
Jeong et al. ⁵⁵	Statewide	NG transmission and distribution emissions	317 (179–455)	4,200 (1,800–9,700)	11,000 (5,200–26,000), 500 (5,200–25,900)
Fischer et al. ²⁵	Statewide	residential appliances steady-state operation/combustion	13.3 (6.6–37.1)	170 (67–790)	480 (192–2,100)
	Statewide	residential whole-house quiescent leaks (i.e., pilot lights, pipes, etc.)	23.4 (13.7–45.6)	310 (140–980)	850 (400–2,600)
	Statewide	residential whole-house total emissions	35.7 (21.7–64.0)	470 (220–1,400)	1,300 (630–3,600)
Lebel et al. ²⁷	Statewide	residential NG stove steady-state off leaks	4.8 (3.1–7.0) ^d	63 (32–150)	170 (90–400)
Jeong et al. ⁵⁶	San Francisco Bay Area	whole-region emissions (primarily attributable to distribution)	(23–38) ^e	(180–370)	(590–1,200)
He et al. 2019 ⁵⁷	Greater Los Angeles	whole-region emissions based on residential and commercial NG consumption	72.8 (67.6–78.0) ^f	850 (590–1,100)	2,200 (1,600–3,000)
SoCalGas ⁵⁸	North San Fernando/Santa Clarita Valleys	utility distribution emissions	0.15 ^g	8.8 (4.5–19)	20 (9.5–50)

^aBTEX emissions are calculated by summing the emissions of the individual compounds—benzene, toluene, ethylbenzene, and all xylenes. ^b95% confidence intervals are calculated by scaling the upper and lower values of the methane estimate from the reported study and the confidence interval of the concentration of the compound from this study. ^cRegional estimates were calculated using regional concentrations of compounds from this study. ^dBased on mean steady-state-off stove emissions of 57.9 (36.3–84; 95% CI) mg CH₄ hr⁻¹. ^eBased on the assumption that NG distribution emissions are proportional to consumption. Represents a leakage rate of 0.3–0.5%. ^fBased on residential and commercial NG consumption in the South Coast Air Basin in 2020 and a leakage rate of 1.4 ± 0.1%. ^gDistribution pipeline emissions in 2020 for zip codes within an ~5 mile radius of Porter Ranch.

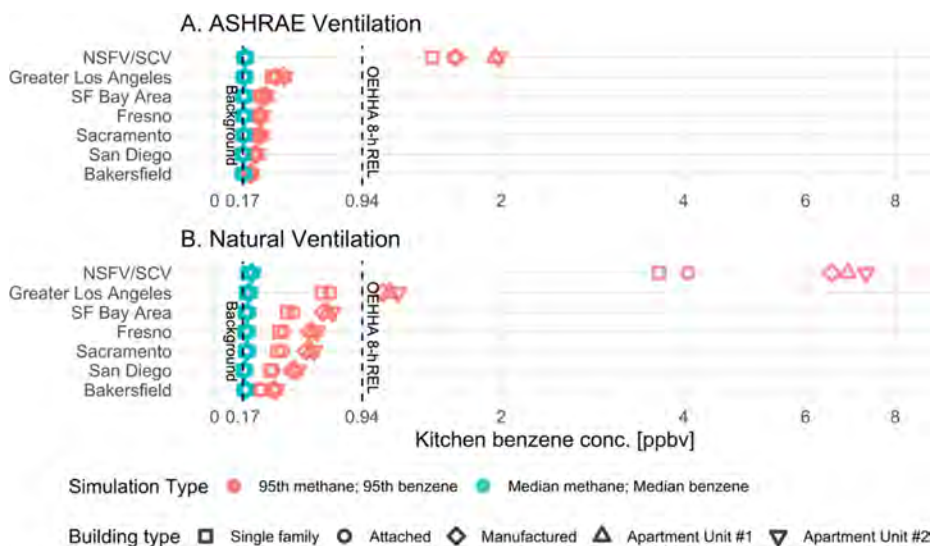


Figure 4. Kitchen indoor air benzene concentration estimates from steady-state-off CONTAM model simulations. Results are for two scenarios of ventilation: ASHRAE standard mechanical ventilation of 0.35 air changes per hour (ACH) and natural ventilation (0.05 to 0.11 ACH). The vertical dashed line shows the California Environmental Protection Agency Office of Environmental Health Hazard Assessment (OEHHA) 8-h and chronic Reference Exposure Level (REL) for benzene (3 $\mu\text{g m}^{-3}$; 0.94 ppb). Median and 95th percentile methane emissions from gas stoves while off (24 and 282 mg hr⁻¹, respectively) are taken from Lebel et al.²⁸ Median and 95th percentile benzene concentrations are taken from this study (Figure 3C,D and Table S3). Building types are shown by various shapes and also have different-sized kitchens ranging from 29–33 m². Apartments 1 and 2 are the same except that Apartment 1 is on the ground floor and Apartment 2 is on the upper floor. Note: Greater Los Angeles does not include samples from the North San Fernando/Santa Clarita Valleys (NSFV/SCV).

SoCalGas distribution pipelines in the North San Fernando and Santa Clarita Valleys alone, where BTEX concentrations were the highest observed (Table S4). These estimates assume that the composition of NG for all sources is relatively stable and do not account for NMVOCs that may be produced or destroyed during the combustion process.^{61–63}

While previous studies have estimated HAP emissions from NG production and development and their implications on air quality,^{64–67} to our knowledge, HAP emissions from leaking

downstream infrastructure and NG appliances are rarely measured and are not included in current inventories. Our regional estimates of benzene emissions in the San Francisco Bay Area (Table 1) are similar to what Michanowicz et al.²⁴ estimated in the Greater Boston Area (120–356 kg benzene yr⁻¹) but are 3–5 times higher in the Greater Los Angeles region.²⁴ Moreover, these inferred NMVOC emissions have likely been misclassified or unaccounted for as sources of

secondary formation of ozone and $\text{PM}_{2.5}$, particularly in nonattainment areas.

Modeled Benzene Kitchen Concentrations. Most model simulations—including all median value simulations—did not result in ambient benzene concentrations attributable to emissions of NG from gas stoves that are off above the California Environmental Protection Agency Office of Environmental Health Hazard Assessment (OEHHA) 8-h REL of 0.94 ppbv (also equal to the chronic REL). However, we found that certain parameter combinations have the potential to lead to exceedances of the OEHHA benzene REL from gas stoves while off (Figure 4).³⁷ Modeled indoor ambient benzene concentrations ranged from 38–126% of the 8-h REL in the Greater Los Angeles region and reached over 700% the REL in the North San Fernando/Santa Clarita Valleys. Notably, all 95th percentile model runs for the NSFV/SCV region resulted in REL exceedances irrespective of ventilation or building type or other indoor sources of benzene. These exceedances produce indoor concentrations of benzene similar to concentrations to environmental tobacco smoke (i.e., secondhand smoke).^{68,69}

Based on model results, an elevated leakage rate of benzene and a low ventilation rate are both requisite for indoor concentrations to exceed the OEHHA 8-h REL for benzene. Using multiple linear regression, we found that the benzene emission rate (benzene concentration times methane flow rate) was the most important factor for determining the kitchen benzene concentration ($p < 0.0001$), followed by the air changes per hour ($p < 0.0001$)—a measure of the air tightness of the space. Interestingly, building size had an insignificant effect on benzene concentration ($p = 0.19$), possibly due to a small number of modeled home sizes. Modeled air changes per hour (ACH) for the natural ventilation simulations ranged from 0.11 for the single-family home to 0.05 for apartments, which has been verified empirically elsewhere (See the [Supporting Information](#) for more details).⁷⁰

There are several reasons our estimates of indoor concentrations of benzene could underestimate true concentrations indoors. First, our calculations were exclusively focused on the contribution of benzene from NG leakage from gas stoves while off and do not include leakage from gas stoves during combustion or incomplete combustion,⁶² other gas appliances (including but not limited to quiescent leakage from other appliances, see Table 1), gas pipes in residence, or other non-NG benzene sources. Second, we included a background ambient benzene concentration of 0.174 ppb for all model runs—the average outdoor ambient concentration in California in 2019.⁷¹ This background benzene concentration may be a conservative measure particularly for some outdoor regions within our study area, and indoor VOCs are generally higher than outdoors to begin with. For example, the South Coast Air Quality Management District (SCAQMD) notes a background outdoor benzene concentration of 0.25 ppb.⁷² We designed our modeling to identify a possible hazard (gas stoves while off only) and recognize that our parameters could lead to underestimating indoor benzene concentrations.

Future Research Directions. Our sampling effort was designed to capture geographic variability rather than temporal variability. While several of our samples were collected in different seasons, our study did not systematically investigate seasonal variability and its associated impacts (e.g., NG demand, withdrawal from underground NG storage facilities,

etc.) on concentrations of NMVOCs in distribution gas. Future work could investigate temporal trends in California in greater depth, as temporal variability was evident in Boston.²⁴ Additionally, while we can infer the various high-volume transmission lines supplying NG regionally in California, we were unable to ultimately source NMVOC composition by upstream source or any potential modifying factors. The highly elevated NMVOC concentrations in distribution NG in the North San Fernando/Santa Clarita Valleys warrant further study to better understand factors contributing to these high concentrations.

Our CONTAM modeling only included emissions of unburned NG leaking from one source: stoves while off. Future work should consider air quality impacts and human health risks of exposure to multiple HAPs and other air pollutants (beyond benzene), emissions of unburned NG from appliances beyond stoves, and indoor emissions from burning NG to build a more complete picture of the potential indoor air quality and health impacts of household NG usage. Additionally, fugitive VOCs from downstream NG systems are likely an under-appreciated contributor to the secondary formation of $\text{PM}_{2.5}$ and ozone—contributing to outdoor air pollution—and should be studied further. As transportation and industry-related VOC emissions continue to decline in urban areas, NG-sourced VOCs may increase in their relative importance as $\text{PM}_{2.5}$ and ozone precursors.

Policy Implications. While there has been substantial research on the health cobenefits of greenhouse gas emission-reduction strategies in transportation, electricity generation, buildings, and industry that has helped inform policy, there is limited research on the health benefits of policies that reduce NG emissions and coemitted air pollutants. This is particularly true in urban areas with many emission sources and in indoor environments where people may be much more frequently exposed to NG-related emissions at higher concentrations. Thus, our study adds to the body of literature that suggests that downstream NG emissions are an unaccounted-for source of both indoor and outdoor emissions of NMVOCs and HAPs. California is already starting to take action to reduce urban pollution from NG: in September 2022, California air regulators approved a commitment to phasing out the sale of NG-fired furnaces and water heaters by 2030. The state has also moved to phase out subsidies for connecting new homes to the NG system, and is considering ending rebates for gas appliances to incentivize the transition to electric alternatives.^{73,74}

In August 2021, the California Energy Commission adopted its 2022 Building Energy Efficiency Standards, which, in part, included differentiated demand-controlled ventilation requirements for electric stoves vs NG-fired stoves.⁷⁵ While this could lead to important improvements in indoor air quality related to combustion-related pollutants (e.g., NO_x , $\text{PM}_{2.5}$, CO_2), this ventilation requirement likely does not impact indoor air quality associated with fugitive, steady-state-off cooking appliance NG emissions—the source-exposure pathway characterized and modeled in this study.

While operating a continuous HVAC system would address nontransitory exposures, it is both cost- and energy-intensive, and retrofitting existing built environments like apartment complexes may not be feasible. Moreover, failing to address indoor pollution sources (e.g., cooking) has been shown to lead to unaccounted-for indoor air quality disbenefits following energy efficiency weatherization such as building sealing.⁷⁶ Our

study suggests that weatherization and building efficiency measures should be coupled with residential and other building electrification measures to support multiple health, air quality, and climate cobenefits by mitigating HAPs and methane emissions while appliances are both off and on.^{77–81} In California, the California Public Utilities Commission (CPUC) pilot programs, TECH and BUILD, aim to reduce the use of NG in the home and provide incentives for all-electric new housing—with the latter program focusing on low-income households.^{82,83} Given the potential air quality impacts and associated health risks from fugitive NG emissions alone—particularly those that may occur indoors—these electrification programs likely entail additional and unaccounted-for health cobenefits and associated long-term cost savings.

■ ASSOCIATED CONTENT

■ Supporting Information

The Supporting Information is available free of charge at <https://pubs.acs.org/doi/10.1021/acs.est.2c02581>.

Details on sample analysis, locations, and pollutant data; details on CONTAM modeling, and summary of public information on California NG sources and storage facilities (PDF)

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Notes

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■ REFERENCES

- (1) US EIA Residential Energy Consumption Survey (RECS): 2020 RECS Survey Data. <https://www.eia.gov/consumption/residential/data/2020/#fueluses>. (accessed July 06, 2022).
- (2) US EIA Natural Gas Explained: Use of Natural Gas. <https://www.eia.gov/energyexplained/natural-gas/use-of-natural-gas.php>. (accessed June 14, 2022).
- (3) US EIA Natural Gas Consumption by End Use. https://www.eia.gov/dnav/ng/ng_cons_sum_dcu_nus_a.htm. (accessed December 22, 2021).
- (4) DiGiulio, D. C.; Jackson, R. B. Impact to Underground Sources of Drinking Water and Domestic Wells from Production Well Stimulation and Completion Practices in the Pavillion, Wyoming, Field. *Environ. Sci. Technol.* **2016**, *50*, 4524–4536.
- (5) Faramawy, S.; Zaki, T.; Sakr, A.-E. Natural Gas Origin, Composition, and Processing: A Review. *J. Nat. Gas Sci. Eng.* **2016**, *34*, 34–54.
- (6) Marrero, J. E.; Townsend-Small, A.; Lyon, D. R.; Tsai, T. R.; Meinardi, S.; Blake, D. R. Estimating Emissions of Toxic Hydrocarbons from Natural Gas Production Sites in the Barnett Shale Region of Northern Texas. *Environ. Sci. Technol.* **2016**, *50*, 10756–10764.
- (7) Pétron, G.; Karion, A.; Sweeney, C.; Miller, B. R.; Montzka, S. A.; Frost, G. J.; Trainer, M.; Tans, P.; Andrews, A.; Kofler, J.; et al. A New Look at Methane and Nonmethane Hydrocarbon Emissions from Oil and Natural Gas Operations in the Colorado Denver-Julesburg Basin. *J. Geophys. Res.: Atmos.* **2014**, *119*, 6836–6852.
- (8) US EPA. *Locating and Estimating Air Emissions from Sources of Benzene*; EPA-454/R-98-011; U.S. Environmental Protection Agency, 1998; p 361.
- (9) Warneke, C.; Geiger, F.; Edwards, P. M.; Dube, W.; Pétron, G.; Kofler, J.; Zahn, A.; Brown, S. S.; Graus, M.; Gilman, J. B.; et al. Volatile Organic Compound Emissions from the Oil and Natural Gas Industry in the Uintah Basin, Utah: Oil and Gas Well Pad Emissions Compared to Ambient Air Composition. *Atmos. Chem. Phys.* **2014**, *14*, 10977–10988.
- (10) Liss, W. E.; Thrasher, W. H.; Steinmetz, G. F.; Chowdiah, P.; Attari, A. *Variability of Natural Gas Composition in Select Major Metropolitan Areas of the United States*, Final Report, August 1990–February 1992, 1992.
- (11) European Commission. Commission Regulation (EU) 2015/1494 of 4 September 2015 Amending Annex XVII to Regulation (EC) No 1907/2006 of the European Parliament and of the Council Concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) as Regards Benzene. *Off. J. Eur. Union* **2015**, *58*, No. 2.
- (12) *Policy Statement on Provisions Governing Natural Gas Quality and Interchangeability in Interstate Natural Gas Pipeline Company Tariffs*, Docket No. PL04-3-000; Federal Energy Regulatory Commission, 2006.
- (13) *FERC Gas Tariff - Third Revised Volume No. 1*; Kern River Gas Transmission Company, 2016.
- (14) PG&E Gas Rule No. 21 - Transportation of Gas 2020.
- (15) SoCal Gas Rule No. 30 - Transportation of Customer-Owned Gas, 2011.
- (16) Texas Eastern Transmission, LP. *FERC Gas Tariff - Eighth Revised Volume No. 1 of Texas Eastern Transmission*, LP2017.

- (17) *Chemical Agents and Related Occupations*, IARC Monographs on the Evaluation of 532 Carcinogenic Risk to Humans; International Agency for Research on Cancer, 2012.
- (18) WHO. *Air Quality Guidelines for Europe, Second Edition*; World Health Organization, 2000.
- (19) USEPA. *Technical Overview of Volatile Organic Compounds*.
- (20) Jimenez, J. L.; Canagaratna, M. R.; Donahue, N. M.; Prevot, A. S. H.; Zhang, Q.; Kroll, J. H.; DeCarlo, P. F.; Allan, J. D.; Coe, H.; Ng, N. L.; Aiken, A. C.; Docherty, K. S.; Ulbrich, I. M.; Grieshop, A. P.; Robinson, A. L.; Duplissy, J.; Smith, J. D.; Wilson, K. R.; Lanz, V. A.; Hueglin, C.; Sun, Y. L.; Tian, J.; Laaksonen, A.; Raatikainen, T.; Rautiainen, J.; Vaattovaara, P.; Ehn, M.; Kulmala, M.; Tomlinson, J. M.; Collins, D. R.; Cubison, M. J.; E; Dunlea, J.; Huffman, J. A.; Onasch, T. B.; Alfarra, M. R.; Williams, P. I.; Bower, K.; Kondo, Y.; Schneider, J.; Drewnick, F.; Borrmann, S.; Weimer, S.; Demerjian, K.; Salcedo, D.; Cottrell, L.; Griffin, R.; Takami, A.; Miyoshi, T.; Hatakeyama, S.; Shimono, A.; Sun, J. Y.; Zhang, Y. M.; Dzepina, K.; Kimmel, J. R.; Sueper, D.; Jayne, J. T.; Herndon, S. C.; Trimborn, A. M.; Williams, L. R.; Wood, E. C.; Middlebrook, A. M.; Kolb, C. E.; Baltensperger, U.; Worsnop, D. R. Evolution of Organic Aerosols in the Atmosphere. *Science* **2009**, *326*, 1525–1529.
- (21) McDonald, B. C.; de Gouw, J. A.; Gilman, J. B.; Jathar, S. H.; Akherati, A.; Cappa, C. D.; Jimenez, J. L.; Lee-Taylor, J.; Hayes, P. L.; McKeen, S. A.; Cui, Y. Y.; Kim, S.-W.; Gentner, D. R.; Isaacman-VanWertz, G.; Goldstein, A. H.; Harley, R. A.; Frost, G. J.; Roberts, J. M.; Ryerson, T. B.; Trainer, M. Volatile Chemical Products Emerging as Largest Petrochemical Source of Urban Organic Emissions. *Science* **2018**, *359*, 760–764.
- (22) USEPA. Benzene.
- (23) Burger, J. L.; Lovestead, T. M.; Bruno, T. J. Composition of the C₆+ Fraction of Natural Gas by Multiple Porous Layer Open Tubular Capillaries Maintained at Low Temperatures. *Energy Fuels* **2016**, *30*, 2119–2126.
- (24) Michanowicz, D. R.; Dayalu, A.; Nordgaard, C. L.; Buonocore, J. J.; Fairchild, M. W.; Ackley, R.; Schiff, J. E.; Liu, A.; Phillips, N. G.; Schulman, A.; Magavi, Z.; Spengler, J. D. Home Is Where the Pipeline Ends: Characterization of Volatile Organic Compounds Present in Natural Gas at the Point of the Residential End User. *Environ. Sci. Technol.* **2022**, *56*, 10258–10268.
- (25) Nordgaard, C. L.; Jaeger, J. M.; Goldman, J.; Shonkoff, S. B. C.; Michanowicz, D. R. Contamination of Transmission Pipeline Natural Gas by Hazardous Air Pollutants: A Systematic Analysis of Industry Disclosures and Data. *Environ. Res. Lett.* **2022**, *17*, 104032.
- (26) Fischer, M. L.; Chan, W. R.; Delp, W.; Jeong, S.; Rapp, V.; Zhu, Z. An Estimate of Natural Gas Methane Emissions from California Homes. *Environ. Sci. Technol.* **2018**, *52*, 10205–10213.
- (27) Lebel, E. D.; Lu, H. S.; Speizer, S. A.; Finnegan, C. J.; Jackson, R. B. Quantifying Methane Emissions from Natural Gas Water Heaters. *Environ. Sci. Technol.* **2020**, *54*, 5737–5745.
- (28) Lebel, E. D.; Finnegan, C. J.; Ouyang, Z.; Jackson, R. B. Methane and NO_x Emissions from Natural Gas Stoves, Cooktops, and Ovens in Residential Homes. *Environ. Sci. Technol.* **2022**, *56*, 2529–2539.
- (29) Crippen, K.; Hill, A.; Baffoe, J.; Glanville, P. *Odorant Effectiveness*; DOT Prj# 363, Contract Number: DTPH56-10-T-000018; Gas Technology Institute, 2013.
- (30) Dalton, P. Psychophysical and Behavioral Characteristics of Olfactory Adaptation. *Chem. Senses* **2000**, *25*, 487–492.
- (31) Larsson, M.; Finkel, D.; Pedersen, N. L. Odor Identification: Influences of Age, Gender, Cognition, and Personality. *J. Gerontol., Ser. A* **2000**, *55*, P304–P310.
- (32) Matsubasa, T.; Gotow, N.; Gomi, Y.; Kobayakawa, T. A Method for Psychophysical Screening of Odorants for Use in City Gas Based on Olfactory Adaptation Tolerance. *Chemosens. Percept.* **2016**, *9*, 120–130.
- (33) Moschandreas, D.; Jones, D.; Martinus, J.; Ragus, E. *Odor Recognition and Fatigue*; IIT Research Inst.: Chicago, IL (USA), 1982.
- (34) Wise, P.; Rowe, S.; Dalton, P. *Odorization of Natural Gas: What Are the Challenges?*, 2021, DOI: 10.1101/2021.07.10.450231.
- (35) Dols, W. S.; Polidoro, B. J. *CONTAM User Guide and Program Documentation Version 3.4*, NIST TN 1887 Rev. 1; National Institute of Standards and Technology, 2020.
- (36) Dols, W. S.; Emmerich, S. J.; Polidoro, B. J. Using Coupled Energy, Airflow and Indoor Air Quality Software (TRNSYS/CONTAM) to Evaluate Building Ventilation Strategies. *Build. Serv. Eng. Res. Technol.* **2016**, *37*, 163–175.
- (37) OEHHA. OEHHA Acute, 8-h and Chronic Reference Exposure Level (REL) Summary. <https://oehha.ca.gov/air/general-info/oehha-acute-8-hour-and-chronic-reference-exposure-level-rel-summary>. (accessed Jul 19, 2022).
- (38) *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air*, 2nd ed.; U.S. Environmental Protection Agency: Cincinnati, OH, 1999.
- (39) *Standard Practice for Analysis of Reformed Gas by Gas Chromatography*, D1946-90R19; ASTM, 2019.
- (40) US EPA. Regional Guidance on Handling Chemical Concentration Data Near the Detection Limit in Risk Assessments: Regional Technical Guidance Manual, Risk Assessment. <https://www.epa.gov/risk/regional-guidance-handling-chemical-concentration-data-near-detection-limit-risk-assessments>. (accessed July 19, 2022).
- (41) Jeong, S.; Millstein, D.; Fischer, M. L. Spatially Explicit Methane Emissions from Petroleum Production and the Natural Gas System in California. *Environ. Sci. Technol.* **2014**, *48*, 5982–5990.
- (42) Jeong, S.; Cui, X.; Blake, D. R.; Miller, B.; Montzka, S. A.; Andrews, A.; Guha, A.; Martien, P.; Bambha, R. P.; LaFranchi, B.; et al. Estimating Methane Emissions from Biological and Fossil-Fuel Sources in the San Francisco Bay Area. *Geophys. Res. Lett.* **2017**, *44*, 486–495.
- (43) He, L.; Zeng, Z.-C.; Pongetti, T. J.; Wong, C.; Liang, J.; Gurney, K. R.; Newman, S.; Yadav, V.; Verhulst, K.; Miller, C. E.; et al. Atmospheric Methane Emissions Correlate with Natural Gas Consumption from Residential and Commercial Sectors in Los Angeles. *Geophys. Res. Lett.* **2019**, *46*, 8563–8571.
- (44) SoCalGas. *Distribution Pipeline Emissions Map*.
- (45) Dols, W. S.; Polidoro, B. J. *CONTAM User Guide and Program Documentation Version 3.2*, NIST TN 1887; National Institute of Standards and Technology, 2015.
- (46) Palmgren, C.; Ramirez, B.; Goldberg, M.; Williamson, C. 2019 *California Residential Appliance Saturation Study (RASS)*, CEC-200-2021-005; California Energy Commission; DNV GL Energy Insights USA, Inc, 2021.
- (47) *Residential Appliance Saturation Study (RASS)*; CEC-200-2021-005; Prepared for California Energy Commission; DNV GL Energy Insights USA, Inc, 2021.
- (48) Persily, A.; Leber, D. *NIST Interagency/Internal Report (NISTIR) 7330, A Suite Of Homes Representing The U.S. Housing Stock*; National Institute of Standards and Technology: Gaithersburg, MD; 2008.
- (49) Seinfeld, J. H.; Pandis, S. N. *Atmospheric Chemistry and Physics: From Air Pollution to Climate Change*, 2nd ed.; John Wiley & Sons, Inc.: Hoboken, NJ, 2006.
- (50) Weschler, C. J.; Shields, H. C. Production of the Hydroxyl Radical in Indoor Air. *Environ. Sci. Technol.* **1996**, *30*, 3250–3258.
- (51) Singer, B. C.; Revzan, K. L.; Hotchi, T.; Hodgson, A. T.; Brown, N. J. Sorption of Organic Gases in a Furnished Room. *Atmos. Environ.* **2004**, *38*, 2483–2494.
- (52) Singer, B. C.; Hodgson, A. T.; Hotchi, T.; Ming, K. Y.; Sextro, R. G.; Wood, E. E.; Brown, N. J. Sorption of Organic Gases in Residential Rooms. *Atmos. Environ.* **2007**, *41*, 3251–3265.
- (53) US EPA. *Health Effects Notebook for Hazardous Air Pollutants*. <https://www.epa.gov/haps/health-effects-notebook-hazardous-air-pollutants>. (accessed November 05, 2021).
- (54) Semptra Energy. *Innovation, Sustainability, and Leadership 2020 Annual Report; 2020 Form 10-K*, 2021.
- (55) *Southwest Gas Corporation; Long Beach Energy Resources Department*, California Gas Report; D.95-01-0392020; Southern California Edison Company, 2020.

- (56) California Gas Report Supplement, D.95-01-039; Long Beach Energy Resources Department, 2021.
- (57) Composition of Natural Gas for Use in the Oil and Natural Gas Sector Rulemaking; USEPA Docket EPA-HQ-OAR-2021-0317-0014; EC/R Inc, 2011.
- (58) Terry, D. Natural Gas Analyses: Chain of Custody 84422; Texas Oil Tech Laboratories, Inc., 2017.
- (59) US EPA. National Emissions Inventory (NEI) Data, 2017. <https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data#data>. (accessed July 19, 2022).
- (60) California Energy Commission. Light-Duty Vehicle Population. <https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics/light-duty-vehicle>. (accessed September 29, 2022).
- (61) Jin, H.; Frassoldati, A.; Wang, Y.; Zhang, X.; Zeng, M.; Li, Y.; Qi, F.; Cuoci, A.; Faravelli, T. Kinetic Modeling Study of Benzene and PAH Formation in Laminar Methane Flames. *Combust. Flame* **2015**, *162*, 1692–1711.
- (62) Senkan, S.; Castaldi, M. Formation of Polycyclic Aromatic Hydrocarbons (PAH) in Methane Combustion: Comparative New Results from Premixed Flames. *Combust. Flame* **1996**, *107*, 141–150.
- (63) Slavinskaya, N. A.; Frank, P. A. Modelling Study of Aromatic Soot Precursors Formation in Laminar Methane and Ethene Flames. *Combust. Flame* **2009**, *156*, 1705–1722.
- (64) Fann, N.; Baker, K. R.; Chan, E. A.; Eyth, A.; Macpherson, A.; Miller, E.; Snyder, J. Assessing Human Health PM_{2.5} and Ozone Impacts from US Oil and Natural Gas Sector Emissions in 2025. *Environ. Sci. Technol.* **2018**, *52*, 8095–8103.
- (65) Francoeur, C. B.; McDonald, B. C.; Gilman, J. B.; Zarzana, K. J.; Dix, B.; Brown, S. S.; de Gouw, J. A.; Frost, G. J.; Li, M.; McKeen, S. A.; Peischl, J.; Pollack, I. B.; Ryerson, T. B.; Thompson, C.; Warneke, C.; Trainer, M. Quantifying Methane and Ozone Precursor Emissions from Oil and Gas Production Regions across the Contiguous US. *Environ. Sci. Technol.* **2021**, *55*, 9129–9139.
- (66) Halliday, H. S.; Thompson, A. M.; Wisthaler, A.; Blake, D. R.; Hornbrook, R. S.; Mikoviny, T.; Müller, M.; Eichler, P.; Apel, E. C.; Hills, A. J. Atmospheric Benzene Observations from Oil and Gas Production in the Denver-Julesburg Basin in July and August 2014. *J. Geophys. Res.: Atmos.* **2016**, *121*, 11055–11074.
- (67) Hendryx, M.; Luo, J. Natural Gas Pipeline Compressor Stations: VOC Emissions and Mortality Rates. *Extr. Ind. Soc.* **2020**, *7*, 864–869.
- (68) Singer, B. C.; Hodgson, A. T.; Nazaroff, W. W. Gas-Phase Organics in Environmental Tobacco Smoke: 2. Exposure-Relevant Emission Factors and Indirect Exposures from Habitual Smoking. *Atmos. Environ.* **2003**, *37*, 5551–5561.
- (69) Nazaroff, W. W.; Singer, B. C. Inhalation of Hazardous Air Pollutants from Environmental Tobacco Smoke in US Residences. *J. Exposure Sci. Environ. Epidemiol.* **2004**, *14*, S71–S77.
- (70) Huangfu, Y.; Lima, N. M.; O’Keeffe, P. T.; Kirk, W. M.; Lamb, B. K.; Walden, V. P.; Jobson, B. T. Whole-House Emission Rates and Loss Coefficients of Formaldehyde and Other Volatile Organic Compounds as a Function of the Air Change Rate. *Environ. Sci. Technol.* **2020**, *54*, 2143–2151.
- (71) California Air Resources Board. Annual Statewide Toxics Summary: Benzene. <https://www.arb.ca.gov/adam/toxics/statpages/benzstate.html>. (accessed July 19, 2022).
- (72) South Coast Air Quality Management District. *MATES V Multiple Air Toxics Exposure Study in the South Coast AQMD*; 2021.
- (73) California Air Resources Board. *Proposed State SIP Strategy*, 2022; 181.
- (74) Adegbesan, A. California Moves to Ban Natural Gas Furnaces and Heaters by 2030. *Los Angeles Times*. <https://www.latimes.com/business/story/2022-09-23/california-moves-to-ban-natural-gas-furnaces-and-heaters-by-2030>. (accessed September 30, 2022).
- (75) California Energy Commission. 2022 Building Energy Efficiency Standards Summary, 2021.
- (76) Underhill, L. J.; Dols, W. S.; Lee, S. K.; Fabian, M. P.; Levy, J. I. Quantifying the Impact of Housing Interventions on Indoor Air

Quality and Energy Consumption Using Coupled Simulation Models. *J. Exposure Sci. Environ. Epidemiol.* **2020**, *30*, 436–447.

(77) Chan, W. R.; Kim, Y.-S.; Less, B. D.; Singer, B. C.; Walker, I. S. Ventilation and Indoor Air Quality in New California Homes with Gas Appliances and Mechanical Ventilation; Lawrence Berkeley National Lab: Berkeley, CA, 2019.

(78) Logue, J. M.; Klepeis, N. E.; Lobscheid, A. B.; Singer, B. C. Pollutant Exposures from Natural Gas Cooking Burners: A Simulation-Based Assessment for Southern California. *Environ. Health Perspect.* **2014**, *122*, 43–50.

(79) Singer, B. C.; Pass, R. Z.; Delp, W. W.; Lorenzetti, D. M.; Maddalena, R. L. Pollutant Concentrations and Emission Rates from Natural Gas Cooking Burners without and with Range Hood Exhaust in Nine California Homes. *Build. Environ.* **2017**, *122*, 215–229.

(80) Zhao, H.; Chan, W. R.; Cohn, S.; Delp, W. W.; Walker, I. S.; Singer, B. C. Indoor Air Quality in New and Renovated Low-Income Apartments with Mechanical Ventilation and Natural Gas Cooking in California. *Indoor Air* **2021**, *31*, 717–729.

(81) Zhu, Y.; Connolly, R.; Lin, Y.; Mathews, T.; Wang, Z. Effects of Residential Gas Appliances on Indoor and Outdoor Air Quality and Public Health; UCLA Fielding School of Public Health: California, 2020.

(82) California Energy Commission. Building Initiative for Low-Emissions Development Program. <https://www.energy.ca.gov/programs-and-topics/programs/building-initiative-low-emissions-development-program>. (accessed July 19, 2022).

(83) California Public Utilities Commission. Decision Establishing Building Decarbonization Pilot Programs; Decision 20-03-027, R.19-01-011, 2020.

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Population Attributable Fraction of Gas Stoves and Childhood Asthma in the United States

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Abstract: Indoor gas stove use for cooking is associated with an increased risk of current asthma among children and is prevalent in 35% of households in the United States (US). The population-level implications of gas cooking are largely unrecognized. We quantified the population attributable fraction (PAF) for gas stove use and current childhood asthma in the US. Effect sizes previously reported by meta-analyses for current asthma (Odds Ratio = 1.34, 95% Confidence Interval (CI) = 1.12–1.57) were utilized in the PAF estimations. The proportion of children (<18 years old) exposed to gas stoves was obtained from the American Housing Survey for the US, and states with available data (n = 9). We found that 12.7% (95% CI = 6.3–19.3%) of current childhood asthma in the US is attributable to gas stove use. The proportion of childhood asthma that could be theoretically prevented if gas stove use was not present (e.g., state-specific PAFs) varied by state (Illinois = 21.1%; California = 20.1%; New York = 18.8%; Massachusetts = 15.4%; Pennsylvania = 13.5%). Our results quantify the US public health burden attributed to gas stove use and childhood asthma. Further research is needed to quantify the burden experienced at the county levels, as well as the impacts of implementing mitigation strategies through intervention studies.



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Keywords: gas; stove; current; use; asthma; burden; cooking; respiratory; children

1. Introduction

Indoor gas stove use for cooking is associated with an increased risk of current asthma among children [1] and is prevalent in 35% of households in the United States (US), with certain states (e.g., California, Illinois) reaching 68% [2]. Although children's exposure to gas cooking is widespread, the population-level implications of cooking with gas are largely unrecognized [3]. With this background, we attempted to quantify the population-attributable fraction (PAF) for gas stove use and current childhood asthma in the US, including at the state level, which had never been done. The PAF can be helpful for determining the proportion of preventable disease and may guide public health interventions that aim to reduce disease risk

2. Materials and Methods

First, we sought to update the effect-size estimates by identifying peer-reviewed manuscripts published subsequent to the most recent meta-analysis [1]. We searched PubMed using keywords: “gas cooking and children” OR “gas appliance and children” OR “unvented and children” OR “gas heating and children” OR “gas heater and children”. After including only manuscripts of human studies published in English since 4 January 2013, 357 studies remained for possible inclusion. The title review identified 27 manuscripts

as potentially pertinent. Full manuscripts ($n = 27$) were independently reviewed by co-authors; none reported new associations between gas stove use and childhood asthma specifically in North America or Europe. As a result, effect sizes previously reported for current asthma in North America and Europe combined (weighted by inverse variance; $N_{\text{studies}} = 10$; Odds Ratio (OR) = 1.34, 95% Confidence Interval (CI) = 1.12–1.57) were utilized in the PAF estimations [1]. The combined effect size was based on a North America-specific effect size ($N_{\text{studies}} = 3$; OR = 1.36, 95% CI = 0.76–2.43) and Europe-specific effect size ($N_{\text{studies}} = 7$; OR = 1.34, 95% CI = 1.13–1.60), as reported in a previously published meta-analysis [1]. We combined effect sizes for North America and Europe given the similarities in housing characteristics and gas-stove usage patterns across these geographies. We estimated the proportion of children (<18 years old) exposed to gas stoves in the US and in certain states using the American Housing Survey (AHS) [2]. The AHS is a nationally representative survey of households used to characterize the residential housing stock of the US. Each year, a subset of states is oversampled, allowing for precise estimates of housing characteristics for these states. In the most recent iteration of the survey in 2019, nine states were oversampled, allowing us to estimate PAFs at the national level and for these nine states.

PAFs were estimated using a previously published approach [4]. The approach aimed to quantify our uncertainty regarding the PAF point estimates, given that the inputs to the calculation are based on samples of the population. First, we used the summary statistics of the North America and Europe combined odds ratio described above to generate a distribution of effect sizes. Similarly, we used the summary statistics of the proportion of children exposed to gas cooking to generate distributions of proportions nationally and for each state for which we have data. We then drew a random value from each of these distributions to calculate the PAF according to the following equation:

$$\text{PAF} = \frac{p \times (RR - 1)}{p \times (RR - 1) + 1}$$

where p is the proportion of households with children exposed to gas stoves and RR is the relative risk of developing asthma given exposure to gas stoves. Note that we used the combined North America and Europe odds ratio for the relative risk in this equation, as childhood asthma in the US remains relatively rare, affecting 1 in 12 children [5]). We repeated this calculation 10,000 times to create distributions of PAFs nationally and for each state, using the same combined odds ratio for national- and state-level calculations. We then took the mean of these distributions and calculated their 95% confidence intervals to estimate the PAF of current childhood asthma attributable to gas stove usage. All calculations were performed using the R programming language.

3. Results

We found that 12.7% (95% CI = 6.3–19.3%) of current childhood asthma in the US is attributable to gas stove use (Figure 1). At the state level, the proportion of childhood asthma that could be theoretically prevented if gas stove use was not present (e.g., state-specific PAFs) varied. Illinois experiences the highest burden (21.1%), followed by California (20.1%), New York (18.8%), Massachusetts (15.4%), and Pennsylvania (13.5%). Texas, Colorado, and Ohio all experience burdens around 10%. Florida experiences the lowest burden (3%). The state-level PAFs differ due to varying exposure to gas stoves among children. In Illinois, for example, approximately 79.1% of households with children cook with gas, whereas in Florida, the figure is only 9.1%. States with a higher percentage of children living in households with gas stoves have higher proportions of current childhood asthma attributable to gas stove usage.

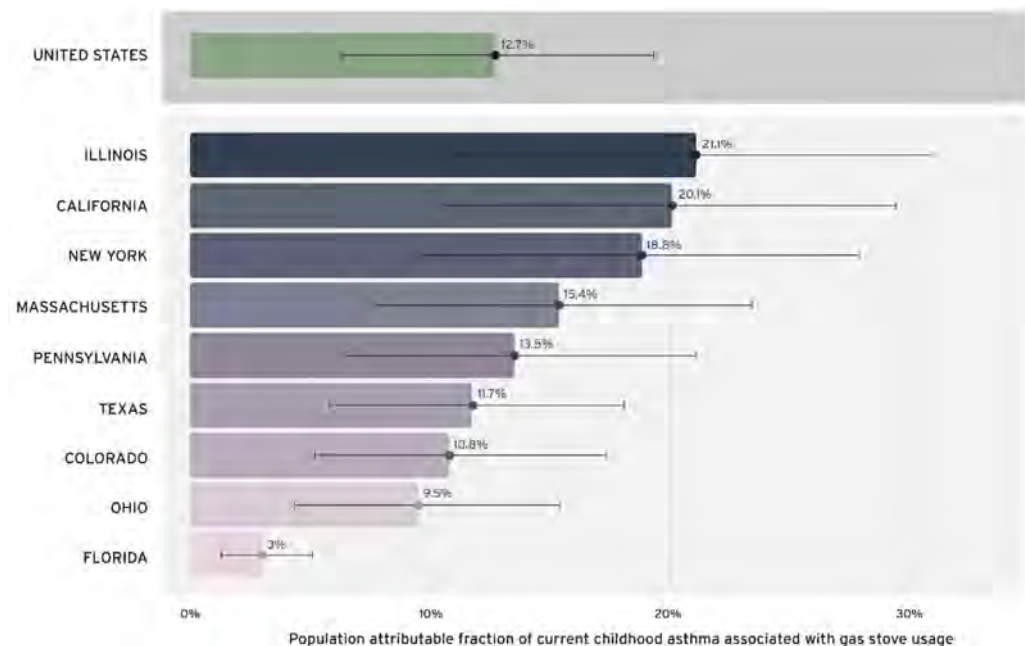


Figure 1. Population attributable fraction (PAF) of current childhood asthma associated with gas-stove use in the United States. PAFs calculated using methods published by Knibbs et al., 2018 [4], with the effect sizes reported by Lin et al., 2013 [1] and the proportion of children (≤ 18 years old) exposed to gas stoves reported by the 2019 American Housing Survey (AHS) [2]. AHS only included information on gas stove use for the nine states included. No data were available for other states.

4. Discussion

Our results quantify the US public health burden attributed to gas-stove use and childhood asthma. Our study strengths include utilization of peer-reviewed effect sizes [1] and existing PAF models [4]. While we are the first to report these PAFs at national and state-specific levels using nationally representative AHS data, we were limited by the number of states ($n = 9$) with available data. Nonetheless, our results align with a cross-sectional study which found that the use of a gas stove or oven for heat was a main risk factor for doctor-diagnosed asthma in US children under age six [6].

We note that PAF analyses have limitations. For example, we rely on aggregate data, although we have quantified our uncertainty and have still found a significant public health burden. Additionally, our interpretation of the PAF as the proportion of preventable disease rests on the assumptions that (1) exposure to gas cooking among children is orthogonal to other risk factors such as exposure to tobacco smoke and (2) that we can conceive of a broad-based public health intervention to reduce the disease risk in children exposed to gas cooking to that of the unexposed, while holding all other risk factors equal.

We posit that there are two such interventions to reduce the childhood asthma disease risk attributable to gas stoves: (1) removing the source by replacing gas cooking with cleaner alternatives (e.g., electric), and (2) reducing exposure by replacing gas cooking with cleaner modes (e.g., fan, electric) and (3) associated with the reduced, source ventilation, (e.g., range hood). Notably, while these interventions have been shown to be a practical means of reducing asthma risk [17], moreover, associated with the reduction in practical means of reducing asthma risk [17], moreover, associated with the reduction in practical means of reducing asthma risk [17], moreover, associated with the reduction in practical means of reducing asthma risk [17].

5. Conclusions

In conclusion, 12.7% of current childhood asthma nationwide is attributed to gas stove use, which is similar to the childhood asthma burden attributed to secondhand smoke

exposure [9]. Gas stove usage should be considered in multi-faceted asthma prevention approaches. Given that this exposure is preventable, our study demonstrates that known mitigation strategies will lessen childhood asthma burden from gas stoves, particularly in states with elevated PAFs. Further research is needed to quantify the burden experienced at the state and county levels, as well as the impacts of implementing mitigation strategies through intervention studies.

Author Contributions: Conceptualization, B.A.S. and H.D.H.III; methodology, L.D.K. and H.D.H.III; formal analysis, T.G.; data curation, T.G.; writing—original draft preparation, T.G.; writing—review and editing, T.G., B.A.S., L.D.K. and H.D.H.III. All authors have read and agreed to the published version of the manuscript.

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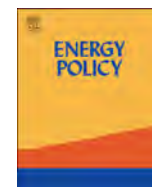
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References

1. Lin, W.; Brunekreef, B.; Gehring, U. Meta-analysis of the effects of indoor nitrogen dioxide and gas cooking on asthma and wheeze in children. *Leuk. Res.* **2013**, *42*, 1724–1737. [CrossRef] [PubMed]
2. American Housing Survey U.S. Census Bureau. 2019. Available online: <https://www.census.gov/programs-surveys/ahs.html> (accessed on 21 July 2021).
3. Krasner, A.; Jones, T.S.; LaRoque, R. Cooking with Gas, Household Air Pollution, and Asthma: Little Recognized Risk for Children. *J. Environ. Health* **2021**, *83*, 14–18.
4. Knibbs, L.D.; Woldeyohannes, S.; Marks, G.B.; Cowie, C.T. Damp housing, gas stoves, and the burden of childhood asthma in Australia. *Med. J. Aust.* **2018**, *208*, 299–302. [CrossRef] [PubMed]
5. Centers for Disease Control and Prevention. Asthma in Children. 2018. Available online: <https://www.cdc.gov/vitalsigns/childhood-asthma/index.html> (accessed on 8 December 2022).
6. Lanphear, B.P.; Kahn, R.S.; Berger, O.; Auinger, P.; Bortnick, S.M.; Nahhas, R.W. Contribution of Residential Exposures to Asthma in US Children and Adolescents. *Pediatrics* **2001**, *107*, e98. [CrossRef] [PubMed]
7. Kile, M.L.; Coker, E.S.; Smit, E.; Sudakin, D.; Molitor, J.; Harding, A.K. A cross-sectional study of the association between ventilation of gas stoves and chronic respiratory illness in U.S. children enrolled in NHANESIII. *Environ. Health* **2014**, *13*, 71. [CrossRef] [PubMed]
8. Seltnerich, N. Take care in the kitchen: Avoiding cooking-related pollutants. *Environ. Health Perspect.* **2014**, *122*, A154–A159. [CrossRef] [PubMed]
9. Abreo, A.; Gebretsadik, T.; Stone, C.A.; Hartert, T.V. The impact of modifiable risk factor reduction on childhood asthma development. *Clin. Transl. Med.* **2018**, *7*, 15. [CrossRef] [PubMed]

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Distributed solar and environmental justice: Exploring the demographic and socio-economic trends of residential PV adoption in California

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ABSTRACT

The rapid growth of distributed solar adoption in California provides an opportunity to lower electricity bills for the adopters and realize additional community benefits, including grid resilience and lower grid emissions. It is unclear, however, whether this transition is occurring equitably across the state's various demographic and socioeconomic groups and whether historically disadvantaged environmental justice (EJ) communities have been able to exploit the bill savings and other associated benefits of rooftop solar. Here we analyze the cumulative and annualized (spatial and temporal) rates of PV adoption across California and compare those with data from the state's cumulative impact EJ methodology (CalEnviroScreen). We find persistently lower levels of PV adoption in disadvantaged communities, suggesting clear distributive and equity impacts of existing PV support policies, and indicating that the benefits bypass some of the state's most vulnerable populations. The analysis reveals strong correlation of solar adoption with not only socioeconomic variables, but also with health, environmental and demographic indicators, contributing to our growing understanding of the role these factors play in household clean-energy adoption trends. The results provide a baseline from which to develop more effective policies, strategically design incentives, and track the efficacy of existing solar programs that target disadvantaged communities.

1. Introduction

Residential photovoltaic (PV) adoption in the US has seen a dramatic increase over the past couple of decades. The state of California leads the nation, both in terms of total number of small-scale PV systems deployed — over 610,000 installations up to 20 kW (kW) in size as of 2018 — and the number of such installations per capita, averaging about one array for every 65 California residents (The OpenPV Project, 2018). The high rate of distributed solar adoption in California has been fueled by a combination of factors: aggressive statewide renewable energy policies aimed at reducing greenhouse gas emissions, strong incentive programs such as the California Solar Initiative (CSI), state and federal PV income tax credits and rebates, net energy metering (NEM) compensatory mechanisms, high solar resource potential throughout the state, falling PV costs, and last but not least, electricity prices that are among the highest in the nation. State government policies, as well as general consumer preferences for cleaner energy, are rapidly transforming the California energy landscape — generation from small-scale solar has grown from 3% to 6.6% of total in-state generation in just the last four years (Electricity Data Browser, 2018). As the state keeps moving towards a power sector with lower overall

greenhouse gas and criteria pollutant emissions, it is also upending the traditional paradigm of electricity generation and distribution by providing some consumers with the opportunity to produce electricity at the point of consumption. However, important questions still remain about whether this transition is occurring equitably across the state's various demographic and socioeconomic groups and whether historically disadvantaged environmental justice communities have been able to capitalize on the bill savings and other associated benefits of distributed solar.

The leveled cost of energy from renewable energy resources has fallen precipitously in recent years (Lazard Ltd, 2018). Early adopter regions of renewable technologies such as California and Germany, however, have faced the unfortunate side effect of increased electricity prices for consumers (Rockzsfforde and Zafar, 2015; Grösche and Schröder, 2014; Jenkins et al., 2016). High residential utility costs can place a disproportionate burden on low-income households. A study by the American Council for an Energy Efficient Economy (ACEEE) found that the median US energy burden, defined as the percent of annual income spent on energy utility bills (electric, gas or other heating fuels), was 3.5% across all major US cities, while the median low-income household's energy burden was more than twice that at 7.2% (Drehobl

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and Ross, 2016). In a large fraction of the cities surveyed, the lowest quarter of low-income households, i.e. the poorest residents, experienced an even greater energy burden of over 14%, substantially higher than the 3.5% average for all US households. Energy burden disparities are often articulated through terms like fuel poverty and energy insecurity, which reflect the inability of a household to meet basic energy needs (Bednar et al., 2017; Hernández, 2013). Concerns related to fuel poverty and energy insecurity constitute the foundation of a growing field of scholarship on energy (in)justice, which revolves around the idea that fuel poverty violates the basic principle of distributive justice (Jenkins et al., 2016; Reames, 2016; Gross, 2007; Sovacool et al., 2016).

Additional environmental, health, and demographic factors often interplay with the socioeconomic aspects of energy insecurity. Evidence suggests that other social stressors besides poverty, including racial discrimination, crime, malnutrition, substance abuse, and numerous environmental and health stressors are often present in communities of lower socioeconomic status (Morello-Frosch et al., 2011; Cushing et al., 2018). Research is also beginning to show how the cumulative effects of these social and environmental vulnerabilities can work in concert to produce both health and equity disparities (Solomon et al., 2016). As a result, regulatory agencies have started to consider new cumulative impact methodologies that incorporate social equity, health and environmental data in policy decision-making (U.S. Environmental Protection Agency, 2017; California Climate Invest, 2019). One such methodology is CalEnviroScreen (CES) introduced by the California Office of Environmental Health Hazard Assessment (OEHHA) in 2013 (CalEPA, 2017). CES is a database and a geospatial mapping tool that integrates environmental burden and socioeconomic data on the census tract level in California. The state of California uses CES to identify disadvantaged communities (DACs) in the state, defined as the census tracts that score in the top 25% statewide on the CalEnviroScreen 3.0 metric. These are the 25% of California communities that suffer the most from a combination of socioeconomic, health and environmental burdens. The CES methodology now plays a key role in directing resources from the California Cap-and-Trade program to support clean energy investments in environmental justice (EJ) communities (S35 Disadvantaged Comm, 2019), with several new statewide initiatives serving as the vehicles for these funds (Solar on Multifamily Affo, 2019; Expanding Solar in Disadv, 2019).

Residential PV adoption can help lower electricity bills for low-income households and make energy expenses more stable from month to month. In addition, environmental justice communities, which are affected by multiple environmental, health and socioeconomic stressors, may see multiple benefits (Cushing et al., 2018). For example, 84% of the peaker power plants in California are sited in locations that have higher than average CES scores, and close to half of these plants are located in disadvantaged communities (top 25% of CES scores) (Krieger et al., 2016). Deployment of rooftop solar in such communities, especially when paired with storage to reduce electricity consumption during peak hours, has the potential to not only lower electricity bills for the adopters, but to also yield co-benefits such as lower air pollutant emissions by displacing local marginal fossil fuel electricity generation in transmission-constrained load pockets (Krieger et al., 2016). Low-income households face numerous barriers to accessing solar power and its economic benefits, including high upfront costs, lack of access to financial instruments, lack of information, language and behavioral barriers, split incentives between owners and tenants (many low-income households are renters), and others. Several state programs in California were initiated with the goal of lowering or removing some of those barriers (Multifamily Affordable So, 2018; Single-Family Affordable, 2018; California Energy Commission, 2016). The emergence of third-party financing models has also provided an avenue to spur PV deployment among low-income households (Drury et al., 2012). To date, however, no studies have rigorously examined PV adoption rates in EJ communities, analyzed the role of various EJ

indicators in PV adoption, or evaluated the cumulative effects of state programs developed to help these communities. To improve the effectiveness of targeted policies, a more in-depth evaluation of the spatial and temporal dynamics of solar adoption in vulnerable populations is needed. The aim of this paper is to fill this gap by providing a comprehensive assessment of the role that EJ, demographic, and socioeconomic factors play in the uptake of solar PV in disadvantaged communities in California.

A significant portion of the research on residential PV diffusion to date has focused on equity issues related to PV policy incentives in countries like Australia (Macintosh and Wilkinson, 2011; Simpson and Clifton, 2016), Germany (Grösche and Schröder, 2014) and the US (Griffith et al., 2014), behavioral and policy reasons for adoption vs. non-adoption of clean energy technologies (Braito et al., 2017; Caird et al., 2008; Kemp and Volpi, 2008; Wilson and Dowlatabadi, 2007; Li and Yi, 2014), or on developing predictive models of consumer behavior (Robinson and Rai, 2015; Rai and Robinson, 2015; Sultan et al., 2016). In recent years, econometric, agent-based, regression and other models have identified key demographic, socioeconomic, and behavioral variables that influence domestic PV diffusion, including income, education, age, ethnicity, family size, owner occupancy, peer effects, and of course, access to financial resources (Kwan, 2012; Sommerfeld et al., 2017; Coffman et al., 2018; Sardianou and Genoudi, 2013; Islam and Meade, 2013; Bollinger and Gillingham, 2012). Models have also looked at the spatial dynamics of PV adoption (Kwan, 2012; Sharshing, 2017; Aklın et al., 2018; Yu et al., 2018). A 2014 study of PV diffusion in California explored how several types of geospatial data, including less-commonly studied variables like house age, number of rooms, and heating source, vary regionally at various spatial scales across the state, and found that regression models using small subsets of geospatial information may be just as predictive as models using hundreds of geospatial variables, but that their predictive powers also depend on the level of spatial resolution and regional characteristics (Davidson et al., 2014). This and other geospatial studies did not explore the temporal dynamics of residential PV adoption. A recent analysis by the Lawrence Berkeley National Lab (LBNL) examined income trends among US residential solar adopters with an emphasis on low- and moderate-income (LMI) residents (Barbose et al., 2018). The report revealed that the median income of residential solar adopters is \$32K higher than that of other households, and \$13K higher compared to owner-occupied households only, but also showed that PV adoption has been trending towards more moderate-income households in recent years. As evidenced by some of the studies referenced above, however, income may not be the only strong driver behind disparities in PV adoption. Importantly, the relative impact of the various demographic and socioeconomic variables is still not well understood, and, to the best of our knowledge, no studies have investigated simultaneously the geospatial and temporal influences of individual and combined EJ indicators within the framework of disadvantaged communities to examine the viability of current EJ methodologies and the policies aimed at helping these communities.

In this paper, we utilize project-level data for the vast majority of residential PV systems in California using LBNL's *Tracking the Sun* database. We chose the state of California for this analysis because: 1) it has the largest number of small-scale PV installations to date and the highest rate of PV adoption per capita in the US; 2) has some of the highest levels of income inequality in the country as well as significant environmental pollution disparities across the state; and 3) has developed a unique and robust environmental justice cumulative impact methodology (CalEnviroScreen) that the state uses to direct clean energy funding streams. We identify key variables within CES and quantify their relative influence on solar adoption both independently and using the combined CES score. We explore geospatial variations of solar adoption on the census tract level and regionally across utility territories, as well as temporal variations of solar adoption within and outside of disadvantaged communities in California over the past 20

years. We aim to answer several key questions: 1) How is distributed solar adoption in California correlated with various socioeconomic and EJ indicators? 2) How have the geospatial, demographic and socioeconomic trends of PV uptake changed over time? 3) What role have state programs designed to help low-income and disadvantaged communities played in solar deployment trends? 4) What are the policy implications of the answers to these questions and what do they say about the EJ methodology used in California (CalEnviroScreen) and its application to climate investments? Our results indicate that EJ communities in California have experienced disproportionately low levels of PV adoption. These low levels of uptake continue to persist to the present day, despite fairly aggressive state policies and a number of solar incentive programs aimed at targeting low-income and disadvantaged communities. Our analysis reveals strong correlation between solar adoption rates and socioeconomic/demographic indicators such as poverty, education, linguistic isolation and housing burden. It also reveals correlation between solar deployment and health/environmental EJ indicators such as asthma rates, cardiovascular disease, low birthweight births and traffic density. These findings contribute to our growing understanding of the role that demographic, socioeconomic, health and environmental factors play in household uptake of clean energy technologies and offer an opportunity to more effectively shape future incentives and policies to successfully target disadvantaged communities in California. They also provide a framework for supporting the equitable deployment of residential solar PV systems and other distributed clean energy technologies nationwide.

2. Data and methodology

This work relies primarily on two data sources. PV deployment data were obtained from the most recent edition of LBNL's Tracking the Sun 2018 database (Darghouth and Barbose, 2018). The dataset includes project-level data for the vast majority of grid-connected non-utility scale PV systems installed nationwide through 2017. LBNL collects the data from state incentive programs, large utilities, state utility regulators and other organizations. For California, our data include 695,620 individual systems within the three largest investor-owned utility (IOU) territories in the state Pacific Gas and Electric (PG&E), Southern California Edison (SCE), and San Diego Gas and Electric (SDG &E). The dataset also contains an additional 50,915 PV systems installed in the two largest public utility service territories in the state: the Los Angeles Department of Water and Power (LADWP) and the Sacramento Municipal Utility District (SMUD). Since individual PV system addresses are not publicly available, LBNL provided us with a list containing the census tract code for each PV installation. This allowed us to aggregate various types of data, including total number of installations, total installed capacity (in kW), customer segment (residential, commercial, government, nonprofit, school, non-residential), and others on the census tract level. It also allowed us to associate the tract-level PV information with the CES 3.0 dataset, which is similarly aggregated on the census tract level. We did not include data for LADWP in our analysis because LADWP data were available to us on the zip code level only.

OEHA's CalEnviroScreen 3.0 is the other primary data source for this analysis. The CES methodology develops an EJ score for each census tract in California based on its state percentile values for 20 different socioeconomic, demographic and environmental indicators. Using percentiles produces a relative, rather than an absolute scale for the pollution impacts and vulnerabilities in California communities, but this approach allows for the aggregation of multiple indicators that are otherwise measured in non-comparable units. The 20 CES indicators are grouped into two broad categories: (1) Population Characteristics, which include five socioeconomic factors (educational attainment, housing burden, linguistic isolation, poverty, unemployment) and three sensitive populations variables (asthma emergency room visits, cardiovascular disease emergency room visits, percent low birthweight

births); and (2) Pollution Burden, which includes seven exposure indicators (ozone and PM_{2.5} concentrations, diesel PM emissions, drinking water contamination, pesticide use, toxic releases, traffic density) and five environmental indicators (cleanup sites, groundwater threats, hazardous waste, impaired water bodies, and solid waste sites) (CalEPA, 2017). The five indicators comprising the Environmental Effects component are weighted one-half when combined with the seven indicators comprising the Exposures component. The overall CES score for each census tract is calculated by (1) averaging the state percentiles of the 12 Pollution Burden indicators and separately averaging the percentiles of the eight Population Characteristics indicators; (2) scaling each of these results to a maximum score of ten; (3) multiplying the population and environmental scores to create an EJ score with a maximum value of 100; and (4) calculating the state percentile of these EJ scores for each census tract. The communities that score in the top 25% of census tracts statewide on this metric and the tracts that do not have an overall CES score but are in the top 5% in the Pollution Burden category are designated as Disadvantaged Communities by the state of California.

We also utilize data from the American Community Survey (ACS) to obtain the 5-year-average (2012–2016) median household income for each census tract. The ACS is a statistical survey conducted by the US Census Bureau that samples a small percent of the US population every year to provide demographic, social and economic data on various communities in the US. ACS provides 1-, 3- and 5-year rolling data but the 5-year ACS data are based on larger survey samples and are considered more reliable.

Due to the distributed nature of small-scale solar systems, in this work we use installed PV capacity per capita as the dependent variable to represent PV adoption rates (or PV deployment density). We use regression and correlational analysis to correlate solar deployment with various demographic, socioeconomic and environmental factors on the census tract level. For parts of the analysis we log-transform the installed PV per capita and use that as the dependent variable in order to produce more normally distributed model residuals.

3. Results and discussion

In this section, we examine the overall geospatial and EJ distribution of PV adoption in California, deployment rates by utility service territory, and the temporal dynamics of solar uptake since 1998. We also correlate PV deployment with predictor variables such as overall CES score, overall Population Characteristics and Pollution Burden scores, as well as several individual indicators from the CES methodology and ACS, including median household income, education level, poverty, unemployment, linguistic isolation, PM_{2.5}, asthma rates and others.

3.1. Spatial and EJ analysis

The geospatial distribution of EJ scores in California and adoption rates of rooftop solar by census tract are compared side-by-side in Fig. 1. Fig. 1a displays the geographic extent of disadvantaged communities in California. The map outlines the broader regional patterns in the state, with most disadvantaged communities located in dense urban areas such as Downtown LA and San Francisco Bay Area (insets), near the smaller metropolitan area of Sacramento, and in the slightly less dense but heavily industrial and agricultural region of the San Joaquin Valley. These communities are colored darker orange on the blue-orange divergent EJ map. Fig. 1b outlines variations in residential PV adoption across census tracts in California. In contrast to the distribution of EJ communities, the geospatial characteristics of rooftop solar (presented on a per capita basis to control for differences in population density) follow a more suburban and rural trajectory. The urban cores of the cities, where most disadvantaged communities are located, reveal relatively low levels of solar uptake, while the outlying

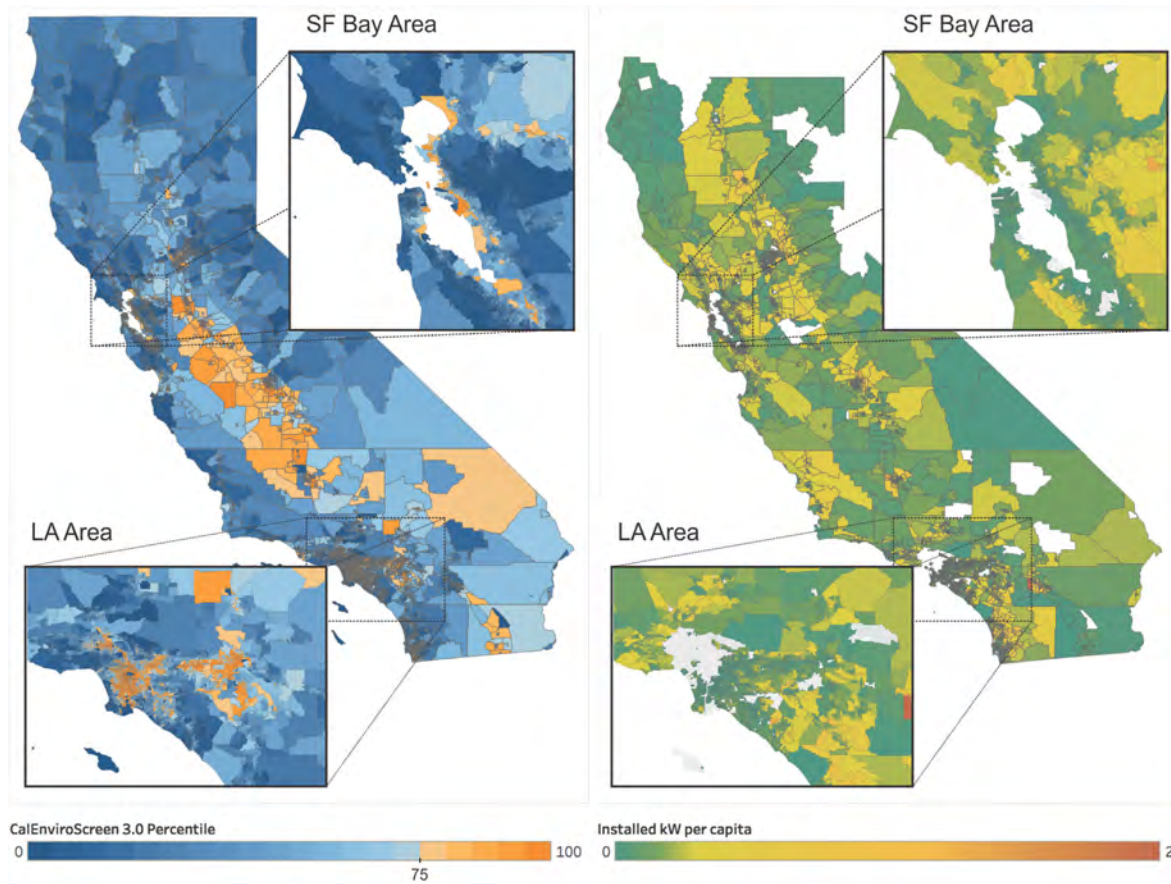


Fig. 1. (a) Geospatial distribution of CES EJ score percentiles in California by census tract. The highest 25% of CES scores are designated as disadvantaged communities (colored orange). (b) Distribution of rooftop solar deployments in California on a green-yellow-orange-red color map. Green indicates lowest rates of solar deployment, yellow-orange indicate medium levels of PV deployment, red indicates highest levels of solar adoption (nearly 2 kW per capita). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

suburbs and rural areas appear to have significantly higher rates of PV adoption. The insets in Fig. 1 illustrate these trends visually for two of the most populous areas in the state: the LA Basin and the San Francisco Bay Area. The census tracts with highest levels of residential PV adoption (colored yellow-red in Fig. 1b) form a spotted band of suburban and rural areas often situated more than 30 miles away from the dense city cores. We note that a large portion of the LA Basin is colored grey on the map due to the unavailability of solar deployment data on the census tract level for LADWP territory. A small number of census tracts overlap both LADWP and SCE territory. In those census tracts, only systems deployed within SCE territory were considered.

CES data are often presented in terms of percentiles rather than CES scores. The percentile rank of each census tract is based on the rank-order of its CES score compared to all other census tracts in the state. Thus, a tract's CES percentile indicates the percentage of census tracts with lower CES scores. In Fig. 2, we plot the cumulative installed PV capacity in kW per capita across the full CES percentile range (0–100) divided into 5% bins. The figure shows rooftop solar deployment data for three major customer segments: residential, commercial and government installations. We excluded non-profit, school and non-residential installations from this figure because they comprise a small percentage of the total kW installed (less than 2% each).

For residential installations, the PV deployment data in Fig. 2 reveals unambiguous tendency towards progressively lower PV adoption levels in communities with higher EJ scores. Rates of residential solar deployment in the most disadvantaged communities, i.e. the census

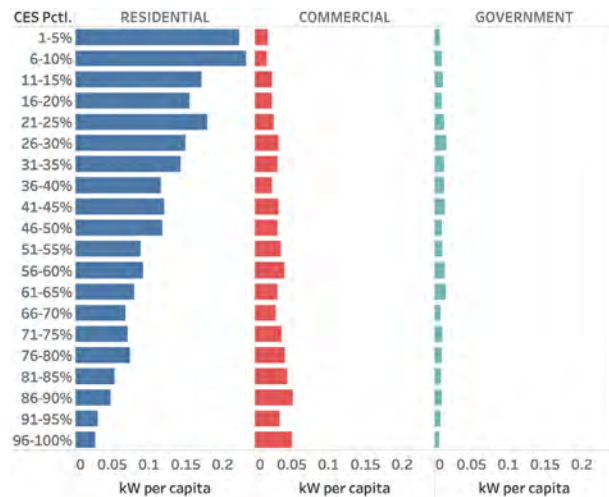


Fig. 2. Total installed rooftop solar (in kW per capita) by CES percentile range divided in 5% bins. Data are shown for three main customer segments: residential (blue), commercial (red), and government (green). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

tracts that rank in the top 5% of CalEnviroScreen, are 8.2 times lower than the adoption rates in the bottom 5% of CES scores (the least disadvantaged communities). To date, only 2.6% of the total residential solar capacity has been installed in the top 10% of CES communities. In contrast, the bottom 10% boast almost 20% of the total residential solar installed to date. The average PV system sizes in the bottom 10% and top 10% CES scores are similar at about 6 kW per system.

In contrast, PV adoption trends for commercial installations are reversed and we see slightly higher installed PV capacity per capita in the higher CES percentile ranges. This finding may be partially attributable to the fact that commercial businesses are often located in industrial and urban areas where environmental burdens are elevated due to high traffic volumes and industrial activities. Government installations reveal a more equal distribution of PV deployment per capita across EJ communities that seems to be largely independent of the EJ score.

The three major IOU territories in California have slightly different solar potential due to their geographic distribution from north to south, with PG&E being the furthest north and SDG&E the southernmost of the three. To account for differences in solar irradiance, as well as for other discrepancies between utilities such as median household income, electricity rates, utility program structures, and percentage of disadvantaged communities, we plot residential solar adoption rates by CES percentile for each of the three main IOU territories. We also include data for the Sacramento Municipal Utility District (SMUD), which is the second largest public utility in California after LADWP. Residential solar adoption rates by utility territory are displayed in Fig. 3.

SDG&E, which tends to serve wealthier populations and contains a smaller percent of disadvantaged communities within its territory, has higher rates of solar adoption per capita in the bottom 25% of CES scores compared to other utilities, but has less PV capacity per capita installed in the top 25% of CES scores (disadvantaged communities). The latter finding is surprising, given that the smaller number of EJ communities in SDG&E territory should, in principle, require less programmatic effort to reach these populations and ensure a more equitable distribution of solar benefits. Only 5.2% of SDG&Es customers live in disadvantaged communities, compared with 30% in SCE, 17.7% in PG&E and 13.3% in SMUD.

In contrast to SDG&E, PG&E and SCE exhibit higher rates of PV adoption in EJ communities, with PG&E claiming the most equitable

distribution of the three IOUs. A significant fraction of the solar capacity installed in PG&E territory falls within the middle CES ranges, although the lowest 10% of CES scores, i.e. the least disadvantaged communities, still show the highest installed PV per capita. SMUD appears to have the lowest overall levels of solar adoption of the four utility territories shown in Fig. 3. This may be due to the convergence of multiple factors, including lower median household income in SMUD territory compared to the three IOUs, different population density, lower electricity rates, and the fact that municipal utilities in California are not subject to the same oversight by the California Public Utilities Commission (CPUC) as compared to the IOUs.

3.2. Temporal dynamics of PV adoption

Figs. 1–3 highlight the total capacity per capita installed in California to date. To explore trends in solar adoption over time, we also examine the annual data time series for the years between 1998 and 2017. Fig. 4 details the evolution of residential solar uptake over the second decade of this period: 2008–2017. The last three years in particular show a marked increase in solar deployment across all CES percentiles. In fact, more than sixty percent (62.8%) of the total residential capacity installed between 1998 and 2017 was deployed in the last three years alone. However, despite the availability of PV support policies in the state of California that have specifically targeted low-income residents in affordable housing, such as the California Solar Initiative and its two main low-income components, the Single-Family Affordable Solar Homes (SASH) and the Multifamily Affordable Solar Housing (MASH) programs, lower rates of solar adoption have continued to persist in the higher CES percentiles.

We analyzed the number of installations installed through SASH and MASH and found that the total PV capacity installed through them is less than 5% of the total residential capacity installed in the state to date. This reported PV capacity reflects the direct impact of the two programs (i.e. the number of directly incentivized deployments) but there may be secondary impacts, such as social diffusion peer effects, which are beyond the scope of this work. Both programs have targeted only low-income households, defined as the households with income of less than 80 percent of the area median income. As a result, systems installed through these programs have been sited both within and outside of disadvantaged communities. While we do note somewhat increased levels of solar diffusion in the higher CES percentiles over the last three years of the dataset, the overall rate of deployment in these populations has remained lower compared to communities with low EJ scores, leading to an ever-widening gap in solar installations between the two ends of the CES spectrum.

This point is further illustrated in Fig. 5, where we plot the total installed residential kW per capita in disadvantaged communities (top 25% of CES scores) versus all other CES percentiles. Fig. 5a compares the running total of cumulative PV installations per capita over the twenty-year period between 1998 and 2017. We note that a gap in installed kW per capita starts to open up very early on and continues to grow until present day. By the end of 2017, the total PV capacity per capita installed outside of disadvantaged communities is almost three times that installed inside them.

Fig. 5b compares the annual rate of solar additions in disadvantaged communities (DACs) versus non-DAC communities as their relative weight of the total installed kW per capita for that year. This means that an equal rate of deployment would be at the 50% mark. In 1998, 1999, all new residential solar deployments occurred outside of disadvantaged communities. In the early years after that, the levels of solar adoption per capita outside of disadvantaged communities were nearly ten times greater than the deployment levels in EJ communities. In the last few years of our dataset, the relative weight of total PV capacity per capita installed in disadvantaged communities has shown a steady increase. This trend is in line with observations by Barbose et al. (2018) who report increased PV adoption rates among low- and moderate-

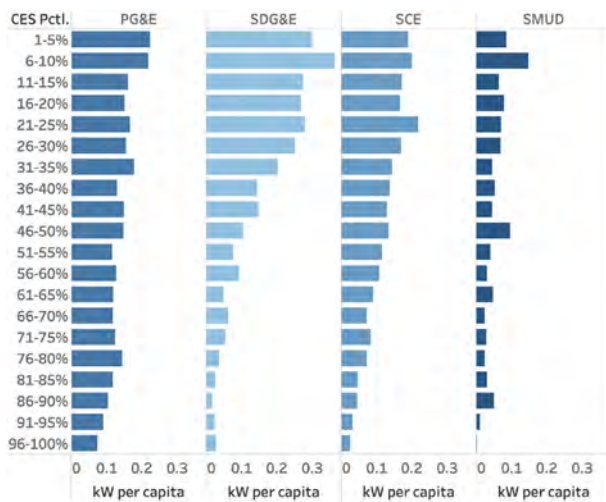


Fig. 3. Residential PV deployment in California (in kW per capita) by CES percentile range. Data shown for four main utility service territories: Pacific Gas and Electric, San Diego Gas and Electric, Southern California Edison, and Sacramento Municipal Utility District.

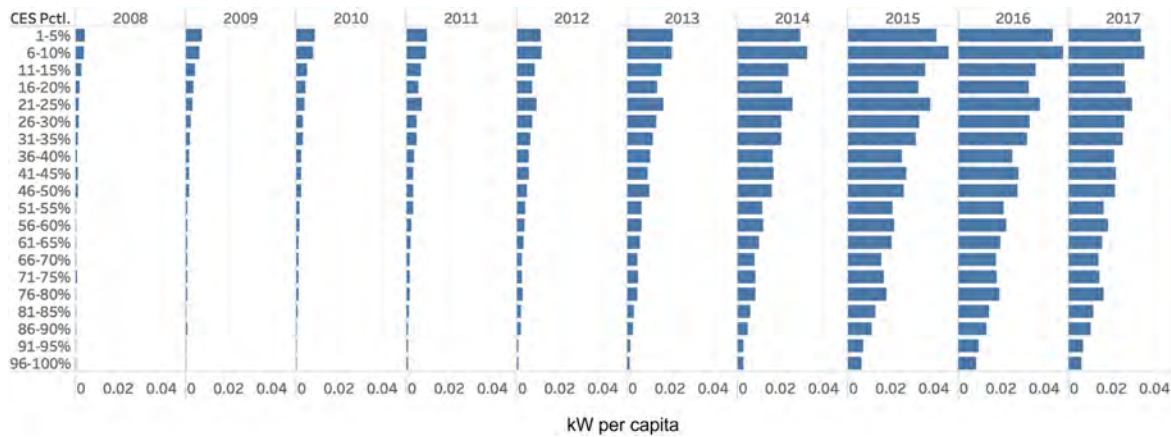


Fig. 4. Installed residential PV in California by year (2008–2017) and by CES percentile range.

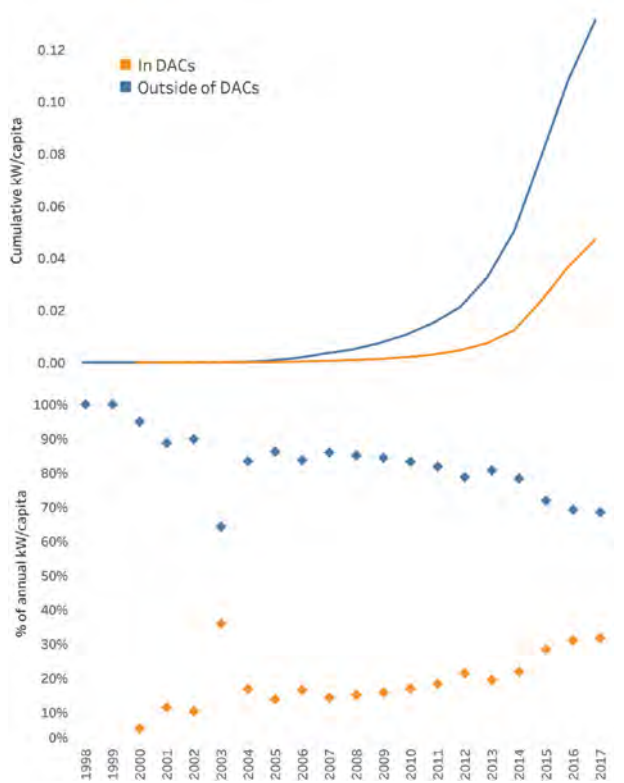


Fig. 5. Installed residential solar in Disadvantaged Communities (DACs) compared to non-DACs. (a) Cumulative running total of installed kW per capita 1998–2017. (b) Relative weight of annual residential solar deployments per capita as percent of the total installed kW per capita for that year. An equal rate of deployment would be at the 50% line. The outlier in 2003 is due to two unusually large residential systems installed in DACs in PG&E territory that year.

income households in recent years. However, even in the last three years of our dataset the kW per capita deployed outside of DACs in California still constitutes the vast majority of installed PV capacity. In 2017, the most recent year in our data, the deployment rate outside of disadvantaged communities was still more than twice the deployment rate in DACs. These numbers suggest that when it comes to distributed solar, the gap between the haves and have-nots in California has continued to increase (albeit at a slower rate) despite aggressive state

policies and a slew of solar incentive programs aimed at targeting low-income communities.

The drivers behind disparities in solar uptake can be complex. As mentioned in the Introduction, previous literature has identified positive association between PV uptake and several socioeconomic and demographic variables, including income, age, education, access to information, perception of risk, neighborhood effects, and others (Wilson and Dowlatabadi, 2007; Kwan, 2012; Barbose et al., 2018; Rai et al., 2016). Home ownership is also a key driver for discrepancies in PV adoption within similar income groups (Barbose et al., 2018).

To evaluate the role of various CES metrics in PV adoption, we explore the relative influence of the overall CES score compared to its two main components that comprise it: Pollution Burden and Population Characteristics. Fig. 6 shows bivariate log-linear scatter plots of the annual installed residential PV capacity per capita across census tracts in California versus each census tract's total CES, Pollution

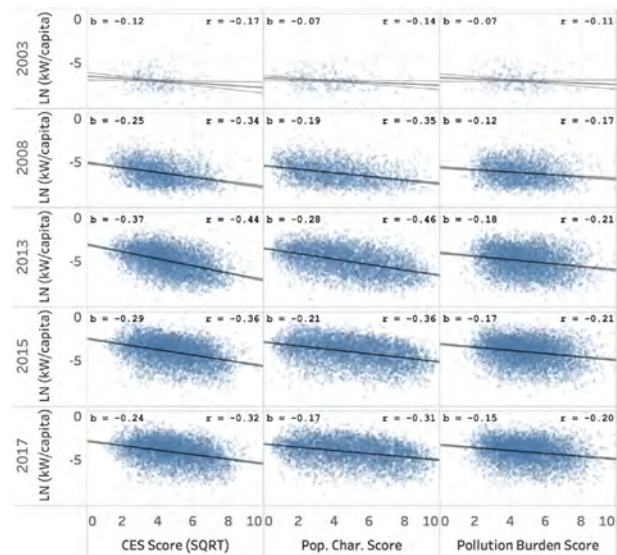


Fig. 6. Bivariate log-linear scatter plots of the residential PV per capita installed in census tracts in California for select years (2003, 2008, 2013, 2015, 2017). Each data point represents a census tract where residential solar was deployed during that year. Data shown as LN (kW/capita) for the total CES score, Population Characteristics Score and Pollution Burden Score. Linear regression models are shown, with b = regression coefficients, r = Pearson correlation coefficients. All are significant at the $p < 0.001$ level.

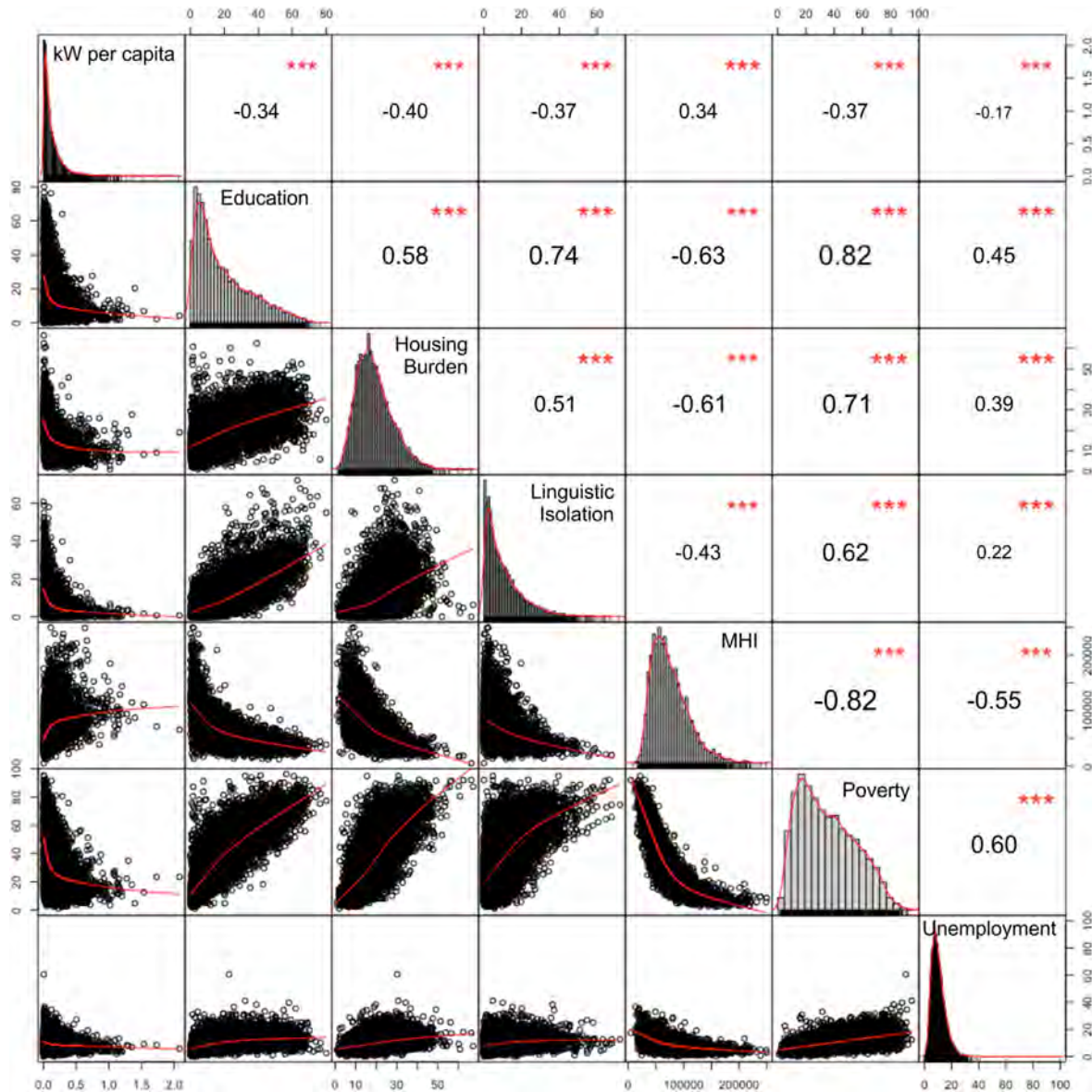


Fig. 7. A correlation matrix for residential solar adoption (kW per capita) and six other independent variables: education, housing burden, linguistic isolation, median household income (MHI), poverty and unemployment. Spearman rank correlation coefficients are displayed to the right of the diagonal. Histogram distributions of the number of census tracts across each variable are shown along the diagonal. Bivariate scatter plots with fitted lines are displayed left of the diagonal. The $p < 0.001$, 0.01 and 0.05 significance levels associated with each coefficient are indicated by three, two, and one stars respectively.

plots represents a single census tract where residential solar was deployed during that year. To illustrate the overall trends over time, we plot the data in five-year intervals early on and then two-year intervals for the most recent years.

We note that census tracts are normally distributed across both the Pollution Burden and Population Characteristics components, which have a score range of 0–10. Census tracts are also normally distributed across the total CES score, calculated by multiplying the Pollution Burden and Population Characteristics components and resulting in a maximum score of 100. We therefore plot the square root of the CES score to obtain a variable directly comparable with the Pollution Burden and Population Characteristics components. Census tracts have a non-normal distribution across the PV deployment variable — a histogram of census tracts ranked by installed PV capacity per capita produces a distribution peaked near the origin (i.e. most census tracts

have little residential solar installed), which decays exponentially at higher rates of PV deployment. We therefore log-transformed the installed kW per capita and used this as the new dependent variable to produce more normally distributed model residuals.

The simple linear regressions shown in the scatter plots in Fig. 6 reveal statistically significant inverse dependence (all significant at the $p < 0.001$ level). The inverse trends are strongest for the overall CES score, slightly less so for the Population Characteristics category, and weakest for the Pollution Burden category. Looking at the annual time series of the scatter plots, we note that the negative regression coefficients b increase over time until 2013, after which they become less influential. The same is true for the Pearson correlation coefficients r . They are generally strongest for the Population Characteristics component, slightly less so for the overall CES score, and weakest for the Pollution Burden component, indicating that Pollution Burden is

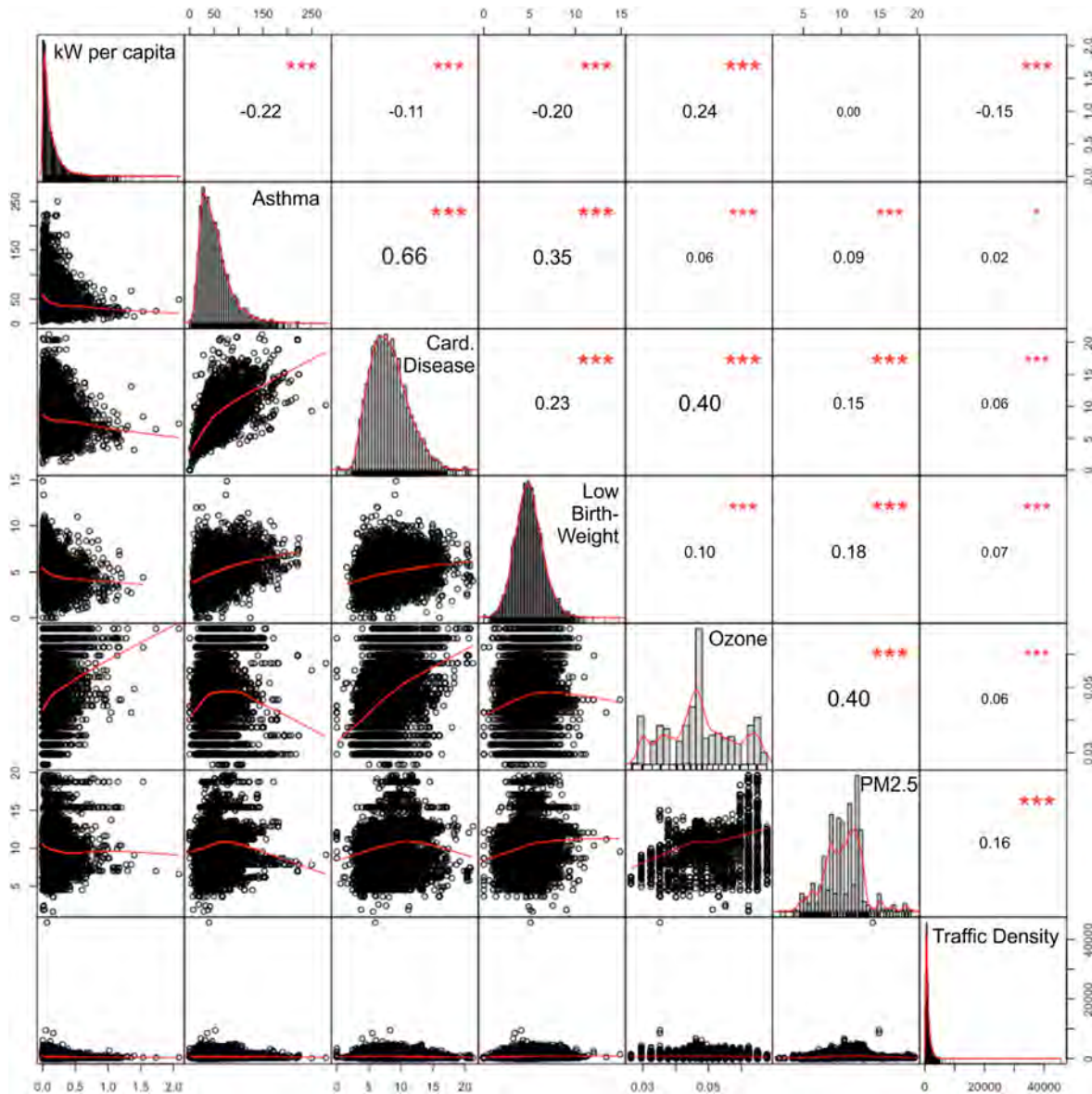


Fig. 8. A correlation matrix for residential solar adoption (kW per capita) and six other independent environmental and health variables: asthma, cardiovascular disease, low birth weight, ozone, PM_{2.5} and traffic. Spearman correlation coefficients are displayed to the right of the diagonal. Bivariate scatter plots with fitted lines are along the diagonal. Histogram distributions of the number of census tracts across each variable are shown along the diagonal. The $p < 0.001$, 0.01 and 0.05 significance levels associated with each coefficient are indicated by three, two, and one stars respectively.

slightly less influential in predicting residential solar adoption rates (but still statistically significant). The results suggest that the Population Characteristics component and the EJ indicators that comprise it are slightly more influential as predictor variables impacting solar PV uptake than the Pollution Burden indicators. To explore this relationship further, we next look at how individual indicators within these two CES categories correlate with residential solar uptake.

3.3. Correlational analysis

We performed both regression and correlational analysis on the individual indicators in our study to examine not only the explanatory ability of these variables but also their relative weight. An ordinary least squares (OLS) multiple regression model for solar adoption was run on our data using all 20 CES indicators plus the median household

income (MHI). Many of these predictor variables, including linguistic isolation, housing burden, MHI, cardiovascular disease, asthma rates, ozone, traffic and others were found to be statistically significant at the $p < 0.001$ level. While regression analysis allows us to control for confounding effects between the explanatory variables, it does not provide clear information about the relative influence of each of the predictor variables on solar adoption rates.

We therefore chose to perform correlational analysis on the two main categories of CES metrics based on the results of the previous section: socioeconomic EJ indicators that comprise the Population Characteristics component in CalEnviroScreen and environmental EJ indicators that comprise the Pollution Burden component. We started by evaluating the Spearman's rank correlation coefficients between residential PV adoption (in kW/capita) and five socioeconomic and demographic variables in the Population Characteristics category:

unemployment, education, housing burden, linguistic isolation and poverty. In CES, the education indicator is defined as the percent of population over age 25 with less than a high school education, housing burden is defined as the percent of households that are both low-income and paying greater than 50% of their income to housing costs, and poverty is defined as the percent of population living below twice the federal poverty level. We also include the 5-year-average (2012–2016) median household income aggregated on the census tract level. The results are summarized in the correlation matrix in Fig. 7 where Spearman's rank correlation coefficients for every pair of variables are displayed. Histogram distributions of the number of census tracts across each variable are also shown along the diagonal, revealing non-normal distributions for all variables. Left of the diagonal are the respective bivariate scatter plots with fitted trend lines, which are generally non-linear. Right of the diagonal are the values of the respective Spearman rank correlation coefficients. The $p < 0.001$, 0.01 and 0.05 significance levels associated with each coefficient are indicated by three, two, and one stars respectively.

All six variables are statistically significant in explaining variations in residential solar adoption across census tracts. Housing burden is the most (inversely) correlated variable with PV adoption (-0.40), followed closely by linguistic isolation (-0.37), poverty (-0.37), low education levels (-0.34) and median household income (0.34). Given the small differences, all five of these variables carry similar weight as predictors, suggesting that a combination of these factors may be more statistically significant in influencing residential solar adoption levels than each of them individually. To test this hypothesis, we generated an index taking the average of the census tract percentiles of the four CES variables most correlated with PV adoption rates — housing burden, linguistic isolation, poverty and education. The Spearman correlation coefficient between the new index variable and kW solar per capita was -0.46 — stronger than for any one of the four variables individually. This correlation is also stronger compared to the overall CES score (-0.34) because the CES score includes the more weakly correlated Pollution Burden component, and compared to the overall Population Characteristics component (-0.37), which contains less correlated indicators such as asthma, cardiovascular disease, and unemployment. Fig. 7 also shows the unemployment indicator, which has a correlation coefficient of -0.17 .

As one might expect, Fig. 7 illustrates strong pairwise correlations between all six explanatory variables. The correlation coefficient between median household income and poverty is -0.82 , between low education and poverty 0.82 , between low education and linguistic isolation 0.74 , and between housing burden and poverty 0.71 . The weakest (but still statistically significant) correlation is between linguistic isolation and unemployment at 0.22 . All coefficients are statistically significant at the $p < 0.001$ level.

In Fig. 8, we also correlate the dependent variable PV deployment per capita with six environmental and health indicators: low birthweight births, ozone, $PM_{2.5}$, traffic, asthma and cardiovascular disease. Five of these variables are statistically significant factors in explaining variations in residential solar adoption between census tracts but with somewhat weaker correlation compared to the demographic and socioeconomic indicators in the Population Characteristics category. The respective correlation coefficients are 0.24 for ozone, -0.22 for asthma, -0.20 for low birth weight, -0.15 for traffic and -0.11 for cardiovascular disease. $PM_{2.5}$ does not end up being a statistically significant predictor variable for residential solar adoption.

3.4. Data significance and limitations

Previous research on the factors influencing solar uptake has focused primarily on socioeconomic considerations and has identified income and home ownership as key explanatory variables for PV adoption (Macintosh and Wilkinson, 2011; Coffman et al., 2018; Barbose et al., 2018). Our analysis suggests that other variables,

including linguistic isolation and education, may be more significant predictors of solar uptake than median household income (at least for data aggregated on the census tract level). Housing burden, linguistic isolation, poverty, education and income all carry nearly equal weights in predicting residential solar adoption rates.

The results also highlight the interrelationship between explanatory variables and indicate that examining combinations of socioeconomic factors using cumulative impact analyses is important for developing a more complete picture of the barriers to solar adoption. The index averaging the census tract percentiles of the CES variables most correlated with PV adoption revealed higher correlation with solar deployment than any of the comprising individual variables. The data also suggest that environmental and pollution burden indicators in the CES methodology (including asthma rates, cardiovascular disease, low birthweight births and traffic density) are statistically significant predictors of solar adoption, albeit slightly less so compared to socioeconomic indicators.

We should emphasize the fact that correlations do not necessarily imply causations. There are numerous confounding demographic and socioeconomic factors that can influence the rates of rooftop solar adoption that were not taken into account in this study. Some of these include degree of home ownership, rural versus urban areas, social diffusion peer effects, and others. We also did not try to account for potential endogeneity effects. We note that home ownership is to some extent reflected in the housing burden CES indicator. We also explored the effects of population density (qualitatively) by arranging census tract data into population density bins and comparing urban versus rural PV adoption rates — we found no significant trends related to the EJ distributional aspects of solar adoption based on population density. The correlations examined in this study, however, do highlight areas where more attention may be needed and where barriers for solar adoption might still exist (e.g. linguistic isolation and education).

Recent studies have indicated that race and ethnicity are important factors for solar adoption in vulnerable communities (Sunter et al., 2019). Research confirms that racial disparities in rooftop PV adoption remain significant even after accounting for income and home-ownership differences (Sunter et al., 2019). Race is no longer used as an indicator in CalEnviroScreen (it was removed after the first iteration of the methodology in order to render CES more practical for state entities prohibited from including racial considerations in their decision-making processes) and, although linguistic isolation can sometimes serve as a proxy for race and ethnicity, the influence of race on solar adoption is not necessarily well represented by this indicator and other population characteristic variables in CES (Liévanos, 2018). The absence of a dedicated race indicator in CalEnviroScreen 3.0 is a limitation, given that CES is used to allocate a quarter of California's carbon Cap-and-Trade funds towards marginalized communities in the state.

We note that the census tract histograms and scatter plots for ozone and $PM_{2.5}$ in Fig. 8 exhibit a peculiar striated pattern. This is an artifact in CES due to the unavailability of hyperlocal data on the census tract level for these two criteria pollutants, which highlights another important limitation in the CES methodology. The low granularity of regional air pollution data means that modeling is generally required to interpolate pollutant concentrations for individual census tracts. Because the models are anchored by a small number of regional air monitoring stations, many census tracts tend to get the same criteria pollutant CES scores, resulting in the striated patterns for ozone and $PM_{2.5}$ seen in Fig. 8. This indicates that data accuracy for these two metrics is not satisfactory at the community level. Collecting hyperlocal pollution data for ozone and $PM_{2.5}$ and achieving higher spatial resolution (ideally on the census tract level) has the potential to considerably improve the CES methodology and in particular the CalEnviroScreen Pollution Burden component.

Geospatial granularity is also an important consideration when analyzing solar data at different geographic aggregation scales. Because clean energy deployment data are not always available on the census

tract level, we ran parts of our analysis for data aggregated on the ZIP code level to test for the effects of lower geospatial granularity on the general findings of this paper. We averaged census tract CES scores within zip codes to obtain a score for each zip code area (this introduces some level of uncertainty because zip code and census tract boundaries do not always align). We then re-ranked zip codes based on their calculated CES scores to obtain a new set of CES percentiles and a new set of disadvantaged communities based on zip code percentiles. We found that the lower granularity of zip code data did change the specific values of correlation coefficients but that the overall trends of solar adoption in EJ communities in California were still captured reasonably well and remained statistically significant. This implies that findings of this study should hold for analyses performed on the zip code level as well, suggesting that zip code data may be sufficiently granular to identify broad trends for the purposes of future research.

Conversely, more granular data on the household level would be highly informative and would allow researchers to explore whether trends observed in this work are mostly community-based or mostly household-based. For instance, solar uptake in education-limited households may be similar across all communities, or worse in communities with low educational levels across the board. Pointers in either direction could inform future policy designs and indicate whether PV support policies should be aimed at identifying disadvantaged communities or disadvantaged households in particular.

3.5. Discussion

The results of this study illustrate an important point about residential solar adoption in California: that there are clear distributive and equity impacts of PV support policies (e.g. net energy metering) and that the benefits of residential PV adoption in California are largely accruing within less-disadvantaged communities and bypassing some of the most vulnerable populations in the state. In addition, the data imply that current climate incentives and state investments in clean energy may not be aligned with equity considerations and environmental pollution trends. Indeed, we should flag a potential concern that has already been raised in previous studies: that in some cases climate incentives can actually be detrimental to equity and public health goals because of increased energy burdens on disadvantaged populations through higher energy prices (Simpson and Clifton, 2016), and because of potentially exacerbated local air pollution due to more frequent ramping of fossil fuel peaker power plants to compensate for the intermittent nature of solar power generation. Peaker power plants in California are disproportionately located in EJ communities (Krieger et al., 2016).

These considerations are important, because residential solar carries the potential to not only address energy disparities by lowering electricity bills through net energy metering and feed-in tariffs, but to also bring additional environmental and health co-benefits to populations that are affected by numerous socioeconomic, environmental and health stressors. The somewhat weaker correlation between pollution/environmental indicators and PV adoption does not necessarily imply that California should ignore communities where EJ scores are elevated primarily as a result of environmental burdens. Rather, we would argue that the rationale for directing investments towards those communities would be slightly different, including targeted support for overburdened populations, or achieving health and pollution-reduction co-benefits rather than focusing solely on the climate and socioeconomic benefits of PV adoption. As mentioned earlier, deployment of distributed solar in combination with efficiency and storage in EJ communities can improve resilience and help displace local fossil fuel generation (Krieger et al., 2016). Delayed participation by disadvantaged communities in this process can exacerbate the disparities between them and other populations in the state.

In line with previous findings, our results suggest that economic burdens — such as housing burden and poverty rates — are likely

significant barriers to solar adoption. In addition, our breakdown of population characteristic metrics suggests that linguistic isolation and low education levels are also highly anticorrelated with solar adoption. Reversing the trends in solar adoption may therefore require both an increase in financial support for low-income populations as well as strategies to specifically target linguistically isolated communities and those with lower levels of education. Ensuring the participation of low-income and linguistically isolated customers in community solar programs can be challenging, and program designs and subscription policies may need to be adjusted compared to standard community solar models by, for example, encouraging affordable housing facilities to serve as subscribers for their tenants, or by using prepaid subscriptions subsidized through state funding, or investing in increased customer outreach, etc. Various third-party financing mechanisms have also proven successful in recent years. In fact, more than two thirds of the SASH and MASH residential installations to date have been financed through third-party financial models.

Future research may need to address limitations in this study related to social diffusion effects, urbanization levels, degree of household ownership, and the lack of high-resolution air pollution data on the census tract level in CES. Future work should also track the impact and effectiveness of new solar support policies and programs for DACs and look at specific programs or strategies that have been particularly effective at reducing inequalities in certain IOUs territories like PG&E. It would be valuable to utilize household-level data to explore whether trends observed in this study are predominantly community-based or household-based. It would also be valuable to explore the distributive justice landscape of other clean energy technologies such as energy storage and energy efficiency.

4. Conclusions and policy implications

The rooftop solar industry in California has experienced dramatic growth in the past four years. In the context of this accelerating deployment, it is critical to evaluate the impacts of PV incentives in the broader context of climate, environmental, public health and equity goals, and improve these policies to maximize the multiple economic, air quality, environmental justice and community resilience benefits that rooftop PV has to offer. As the solar industry continues to grow and solar-adopting states like California continue to refine their next steps in energy policy, it is important that this development is both inclusive and just in order to maximize this resource potential as well as the number of people that have access to its benefits.

In this paper, we analyzed distributed solar adoption in California in the context of environmental justice communities and the applicability of cumulative impact methodologies such as CalEnviroScreen to climate investments in clean energy technologies. We found significantly lower levels of PV adoption in communities that are disadvantaged and suffer from a combination of socioeconomic, health and environmental burdens. We have shown that without intervention, the solar adoption gap between EJ and other communities will likely continue to increase. This underscores the importance of state programs aimed at reaching disadvantaged communities in California.

The state has already taken steps to correct its course. Cap-and-Trade funding streams have been established for several new programs designed to target EJ populations in the state: the new Solar on Multifamily Affordable Housing program (SOMAH) is funded at substantially higher levels compared to the previous MASH program; a new SASH program for disadvantaged communities (DAC-SASH) will target single family low-income homes located in DACs; and two Green Tariff programs — for DACs and for community solar respectively — will provide electricity bill discounts for low-income customers who live in DACs and for community solar projects located in and serving disadvantaged communities. These programs can provide important incentives for solar growth in EJ communities but are still in their nascent stage. Because net energy metering has been one of the most influential

policy drivers in support of rooftop solar adoption in California, it is still unclear whether the new programs will have a significant impact on decreasing inequities in solar access and ensuring that solar co-benefits such as bill savings reach all customers. The effectiveness of the programs should be carefully monitored in the near future and this paper provides a baseline from which to track their efficacy.

Community solar may prove to be an attractive policy instrument for increasing access to solar and reducing solar burdens. Cap-and-Trade funds may ultimately need to be directed towards this sort of solution if individual residential barriers in disadvantaged communities continue to prove challenging. However, community solar may be most viable in urban neighborhoods where significant industrial or commercial rooftop space is available nearby to use for project installations or in more rural EJ areas with readily available land, whereas different policy solutions may be needed in dense urban areas with many apartments and little rooftop space. In such areas, Community Choice Aggregations with carve-outs for LMI customers may be the best option to provide clean energy from resources that are not necessarily located in the vicinity of those neighborhoods.

The results of this analysis may hold policy implications for other non-solar distributed energy resources, including energy efficiency, storage, and demand response (DR) programs. The solar deployment trends examined here highlight the need to design effective incentives for storage and DR while these technologies are still in the early stages of adoption to ensure that their growth does not follow similar inequitable deployment trends. The strategies used to overcome barriers to solar deployment in low-income and disadvantaged communities will likely be effective for other distributed energy technologies, as well as other states and contexts outside of California.

This study also provided insights into the relative influence of various CES indicators on the levels of residential solar adoption. The results confirm the importance of socioeconomic factors such as housing burden, poverty levels and income but also highlight the significance of demographic variables such as linguistic isolation and education, as well as the relevance of health and environmental burden indicators such as traffic pollution, cardiovascular disease and asthma rates. The combination of all these indicators is ultimately important in determining the cumulative barriers to and understanding the drivers behind participation in the adoption of clean energy technologies. Failure to account for these various effects may misdirect efforts to promote environmental health and equity in vulnerable EJ communities that are most in need of regulatory and investment interventions.

For policy makers, our results highlight the value of cumulative impact methodologies like CES. The implications largely rest in the distributive impacts of clean energy technology adoption as a result of energy rate-based compensatory mechanisms and other incentives, and in the question of how to bring the multiple benefits of clean energy technologies to the broadest possible set of customers. The examples that California sets in this regard will hold lessons for other regions in the US in the years to come. While California continues to lead the nation in solar adoption, it should do so by also addressing these important equity issues.

Acknowledgements

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References

- SB 535 Disadvantaged Communities. . <https://oehha.ca.gov/calenviroscreen/sb535>.
- Aklin, M., Cheng, C.-y., Urpelainen, J., 2018. Geography, community, household: adoption of distributed solar power across India. *Energy for Sustainable Development* 42, 54–63.
- Barbose, G., Darghouth, N., Hoen, B., Wiser, R., 2018. Income Trends of Residential PV Adopters: an Analysis of Household-Level Income Estimates. Tech. Rep.. Lawrence Berkeley National Lab (LBNL).
- Bednar, D.J., Reames, T.G., Keoleian, G.A., 2017. The intersection of energy and justice: modeling the spatial, racial/ethnic and socioeconomic patterns of urban residential heating consumption and efficiency in Detroit, Michigan. *Energy Build.* 143, 25–34.
- Bollinger, B., Gillingham, K., 2012. Peer effects in the diffusion of solar photovoltaic panels. *Mark. Sci.* 31 (6), 900–912.
- Braitto, M., Flint, C., Muhar, A., Penker, M., Vogel, S., 2017. Individual and collective socio-psychological patterns of photovoltaic investment under diverging policy regimes of Austria and Italy. *Energy Policy* 109, 141–153.
- Caird, S., Roy, R., Herring, H., 2008. Improving the energy performance of UK households: results from surveys of consumer adoption and use of low-and zero-carbon technologies. *Energy Efficiency* 1 (2), 149.
- CalEPA, 2017. CalEnviroScreen 3.0. Tech. Rep.. California Environmental Protection Agency (CalEPA). <https://oehha.ca.gov/media/downloads/calenviroscreen/report/ces3report.pdf>.
- California Climate Investments to Benefit Disadvantaged Communities. . <https://calepa.ca.gov/envjustice/ghginvest/>.
- California Energy Commission, 2016. SB 350 Barriers Study. Tech. Rep.. California Energy Commission (CEC). https://www.energy.ca.gov/sb350/barriers_report/.
- Coffman, M., Allen, S.F., Wee, S., 2018. Determinants of Residential Solar Photovoltaic Adoption. Tech. Rep.. The Economic Research Organization at the University of Hawai'i.
- Cushing, L., Blaustein-Rejto, D., Wander, M., Pastor, M., Sadd, J., Zhu, A., Morello-Frosch, R., 2018. Carbon trading, co-pollutants, and environmental equity: evidence from California's cap-and-trade program (2011–2015). *PLoS Med.* 15 (7), e1002604.
- Darghouth, N., Barbose, G., 2018. Tracking the Sun. Tech. Rep.. Lawrence Berkeley National Lab (LBNL). <https://emp.lbl.gov/tracking-the-sun>.
- Davidson, C., Drury, E., Lopez, A., Elmore, R., Margolis, R., 2014. Modeling photovoltaic diffusion: an analysis of geospatial datasets. *Environ. Res. Lett.* 9 (7), 074009.
- Drehobl, A., Ross, L., 2016. Lifting the High Energy Burden in America's Largest Cities: How Energy Efficiency Can Improve Low Income and Underserved Communities. Tech. Rep.. ACEEE.
- Drury, E., Miller, M., Macal, C.M., Graziano, D.J., Heimiller, D., Ozik, J., Perry IV, T.D., 2012. The transformation of southern California's residential photovoltaics market through third-party ownership. *Energy Policy* 42, 681–690.
- Electricity Data Browser. . <https://www.eia.gov/electricity/data/browser/>.
- Expanding Solar in Disadvantaged Communities. . <http://www.cpuc.ca.gov/General.aspx?id=6442456661>.
- Griffith, A.B., Higgins, M.R., Turner, J.M., 2014. A rooftop revolution? A multi-disciplinary analysis of state-level residential solar programs in New Jersey and Massachusetts. *J. Environ. Soc. Sci.* 4 (2), 163–171.
- Grösche, P., Schröder, C., 2014. On the redistributive effects of Germany's feed-in tariff. *Empir. Econ.* 46 (4), 1339–1383.
- Gross, C., 2007. Community perspectives of wind energy in Australia: the application of a justice and community fairness framework to increase social acceptance. *Energy Policy* 35 (5), 2727–2736.
- Hernández, D., 2013. Energy Insecurity: A Framework for Understanding Energy, the Built Environment, and Health Among Vulnerable Populations in the Context of Climate Change.
- Islam, T., Meade, N., 2013. The impact of attribute preferences on adoption timing: the case of photo-voltaic (PV) solar cells for household electricity generation. *Energy Policy* 55, 521–530.
- Jenkins, K., McCauley, D., Heffron, R., Stephan, H., Rehner, R., 2016. Energy justice: a conceptual review. *Energy Research & Social Science* 11, 174–182.
- Kemp, R., Volpi, M., 2008. The diffusion of clean technologies: a review with suggestions for future diffusion analysis. *J. Clean. Prod.* 16 (1), S14–S21.
- Krieger, E.M., Casey, J.A., Shonkoff, S.B., 2016. A framework for siting and dispatch of emerging energy resources to realize environmental and health benefits: case study on peaker power plant displacement. *Energy Policy* 96, 302–313.
- Kwan, C.L., 2012. Influence of local environmental, social, economic and political variables on the spatial distribution of residential solar PV arrays across the United States. *Energy Policy* 47, 332–344.
- Lazard Ltd, 2018. Lazard's Levelized Cost of Energy Analysis: Version 12.0. Tech. Rep.. Lazard Ltd., New York.
- Li, H., Yi, H., 2014. Multilevel governance and deployment of solar PV panels in US cities. *Energy Policy* 69, 19–27.
- Liévanos, R., 2018. Retooling CalEnviroScreen: cumulative pollution burden and race-based environmental health vulnerabilities in California. *Int. J. Environ. Res. Public Health* 15 (4), 762.
- Macintosh, A., Wilkinson, D., 2011. Searching for public benefits in solar subsidies: a case study on the Australian government's residential photovoltaic rebate program. *Energy Policy* 39 (6), 3199–3209.
- Morello-Frosch, R., Zuk, M., Jerrett, M., Shamasunder, B., Kyle, A.D., 2011. Understanding the cumulative impacts of inequalities in environmental health: implications for policy. *Health Aff.* 30 (5), 879–887.
- Multifamily affordable solar housing (MASH) program. <http://www.cpuc.ca.gov/general.aspx?id=3752>.

- Rai, V., Robinson, S.A., 2015. Agent-based modeling of energy technology adoption: empirical integration of social, behavioral, economic, and environmental factors. *Environ. Model. Softw* 70, 163–177.
- Rai, V., Reeves, D.C., Margolis, R., 2016. Overcoming barriers and uncertainties in the adoption of residential solar PV. *Renew. Energy* 89, 498–505.
- Reames, T.G., 2016. Targeting energy justice: exploring spatial, racial/ethnic and socio-economic disparities in urban residential heating energy efficiency. *Energy Policy* 97, 549–558.
- Robinson, S.A., Rai, V., 2015. Determinants of spatio-temporal patterns of energy technology adoption: an agent-based modeling approach. *Appl. Energy* 151, 273–284.
- Rockzsforde, R., Zafar, M., 2015. Comparative Analysis of Utility Services and Rates in California. *Tech. Rep.* California Public Utilities Commission.
- Sardianou, E., Genoudi, P., 2013. Which factors affect the willingness of consumers to adopt renewable energies? *Renew. Energy* 57, 1–4.
- Sharshing, S., 2017. Household dynamics of technology adoption: a spatial econometric analysis of residential solar photovoltaic (PV) systems in Germany. *Energy Research and Social Science* 23, 113–124.
- Simpson, G., Clifton, J., 2016. Subsidies for residential solar photovoltaic energy systems in Western Australia: distributional, procedural and outcome justice. *Renew. Sustain. Energy Rev.* 65, 262–273.
- Single-family affordable solar homes (SASH) program. <http://www.cpuc.ca.gov/general.aspx?id=3043>.
- Solar on Multifamily Affordable Housing (SOMAH). . <http://www.cpuc.ca.gov/general.aspx?id=6442454736>.
- Solomon, G.M., Morello-Frosch, R., Zeise, L., Faust, J.B., 2016. Cumulative environmental impacts: science and policy to protect communities. *Annu. Rev. Public Health* 37, 83–96.
- Sommerfeld, J., Buys, L., Mengersen, K., Vine, D., 2017. Influence of demographic variables on uptake of domestic solar photovoltaic technology. *Renew. Sustain. Energy Rev.* 67, 315–323.
- Sovacool, B.K., Heffron, R.J., McCauley, D., Goldthau, A., 2016. Energy decisions re-framed as justice and ethical concerns. *Nature Energy* 1 (5), 16024.
- Sultan, V., Alsamani, B., Alharbi, N., Alsuhaibany, Y., Alzahrani, M., 2016. A predictive model to forecast customer adoption of rooftop solar. In: 2016 4th International Symposium on Computational and Business Intelligence (ISCBI). IEEE, pp. 33–44.
- Sunter, D.A., Castellanos, S., Kammen, D.M., 2019. Disparities in rooftop photovoltaics deployment in the United States by race and ethnicity. *Nature Sustainability* 2 (1), 71.
- The OpenPV Project. . <https://openpv.nrel.gov>.
- U.S. Environmental Protection Agency, 2017. EJSCREEN: Environmental Justice Mapping and Screening Tool, EJSCREEN Technical Documentation. U.S. Environmental Protection Agency (EPA). https://www.epa.gov/sites/production/files/2017-09/documents/2017_ejscreen_technical_document.pdf.
- Wilson, C., Dowlatabadi, H., 2007. Models of decision making and residential energy use. *Annu. Rev. Environ. Resour.* 32, 169–203.
- Yu, J., Wang, Z., Majumdar, A., Rajagopal, R., 2018. DeepSolar: a machine learning framework to efficiently construct a solar deployment database in the United States. *Joule* 2 (12), 2605–2617.



Energy Technologies Area

Lawrence Berkeley National Laboratory

Income Trends of Residential PV Adopters

An analysis of household-level income estimates

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Outline

- Overview and Background
- Data
- Results
 - Median incomes of PV adopters vs. broader population
 - Income distribution of PV adopters
 - LMI adoption rates
 - LMI adopter characteristics
- Conclusions
- Appendix

Project Overview

Objective: Describe income trends among U.S. residential solar adopters, highlighting trends related to low- and moderate-income (LMI) households

Unique features of this analysis

- **Household-level income estimates:** Experian* address-level income estimates allows for more-precise characterization of PV-adopter incomes
- **Relatively extensive coverage of the U.S. solar market:** Based on Berkeley Lab's latest *Tracking the Sun (TTS)* dataset, covering ~82% of the total U.S. market (with street addresses for ~63% of the market)

Scope

- **Rooftop solar on single-family homes:** Underlying data consist primarily of single-family rooftop PV, but later work may extend analysis to multi-family homes and also to community solar subscribers
- **Systems installed through 2016 in 13 states:** Focuses on states in latest TTS dataset with address data available for large fraction of the market; later work may evaluate more-recent adopters and additional states
- **Basic descriptive trends:** Focus here is on establishing basic trends, but later work may examine underlying causal factors more directly, using more-sophisticated statistical methods



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This work seeks to refine and expand upon prior analyses of PV adopter income trends

- Prior analyses have examined PV-adopter income and other demographic trends:
 - Kevala, Center for American Progress, GTM and PowerScout, UC Energy Institute, CT Green Bank, Energy+Environmental Economics, SolarPulse, NREL, others
- Though their data and methods vary, these prior studies generally:
 - Focus on somewhat limited geographies (single states or several larger state markets)
 - Rely on median incomes at the block-group or zip-code level as proxies for individual PV-adopter incomes (or, in limited cases, survey data from a sample of households)
 - Are somewhat dated
- These studies have yielded mixed results and messages:
 - Some show that PV adopters tend to be more affluent and educated than non-adopters, while perhaps highlighting an attenuation of this trend over time
 - Others emphasize that middle-class adopters are most common and that their numbers have risen over time
 - Varying conclusions about the role of TPO in driving LMI adoption

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Analysis builds off *Tracking the Sun (TTS)*

- TTS 10 dataset (August 2017 release)
 - System-level PV data through 2016
 - ~1.1 million residential systems in total
 - >800,000 systems with street addresses
- This analysis focuses on the 13 states with relatively complete address-level coverage (listed in table to the right)
 - Sample represents 89% of all residential systems in the 13 states covered, and 61% of all U.S. residential systems installed cumulatively through 2016
 - Missing from the analysis are a number of relatively large state residential markets: AZ, CO, HI, MD, NJ

See appendix for additional details on data sources and sample sizes by installation year

State	Analysis Sample Residential systems in TTS dataset with addresses <u>and</u> matched to Experian data	Market Coverage Percent of all state residential systems through 2016 in analysis sample
CA	595,847	92%
CT	18,989	82%
DC	2,573	94%
MA	61,422	95%
MN	597	26%
NC	4,697	93%
NM	10,591	87%
NV	20,150	85%
NY	47,343	64%
OH	1,765	66%
OR	11,684	94%
RI	1,936	97%
VT	3,559	59%
Total	781,153	89%

Notes: Market Size is based on maximum value reported across three sources: EIA Form 861 data, GTM Solar Market Insight, and TTS 10. **MN:** Analysis sample consists solely of projects installed through the Made in Minnesota program, representing roughly 50% of statewide installations over the 2014-2016 period. **VT:** Analysis sample consists primarily of installations through 2015; much of the gap in market coverage is thus associated with 2016 installations.

Experian household income estimates

Used to characterize income of PV households

- All PV addresses geocoded and sent to Experian for matching
 - Person- or household-level match for 77% of PV addresses
 - Zip+4 match for 23% (zip+4 is one side of one block of a street—typically ~5-10 households)*
 - <1% not matched
- Experian household income estimates
 - Estimated using individual, household and neighborhood level data via an algorithm designed to predict multiple income levels
 - Validation steps include numerous data comparisons and iterations to increase predictive accuracy and outcome
 - Estimates are fit to census income distribution nationally and at a small geographic level (Census Block Group)

**We conducted robustness checks and found no material or consistent difference in PV-adopter income trends when excluding addresses for which income was matched based on zip+4, rather than an exact household-match*

Census data

Used to characterize income of broader population

- American Community Survey (ACS) 2016 5-year averages
 - Downloaded from factfinder.census.gov
- Analysis makes use of variables relating to household median income, household income distributions, and owner occupied / renter status
 - Depending on the element of our analysis, we use Census data published at the level of the block group (BG), county, Metropolitan/Micropolitan Statistical Area (MSA), or state
 - Variables associated with each PV system by first matching the system address to a census block, which then determines its BG, county, and MSA
- PV adopters classified as LMI based on income relative to Area Median Income (AMI)
 - AMI is calculated from Census data, based on MSA median household income (for urban addresses) or county median household income (for rural addresses)
- Experian income data is fit to Census data, implicitly allowing comparability

A note on defining the “reference” population

- Throughout the analysis, PV adopters are compared or characterized relative to some “reference” population
- These reference populations can vary according to their geographical scope
 - Our analysis uses reference populations based on MSAs, states, and the collection of all states
- Reference populations can also be defined in terms of sub-populations within a given geographical area
 - We consider reference populations based on: (a) *all households* (HH) as well as (b) just *owner-occupied households* (OO-HH)
 - Ideally, we would also use reference populations based on just *owner-occupied, single-family households* (as most PV adopters fall within this group), but Census data do not provide income segmented by single vs. multi-family

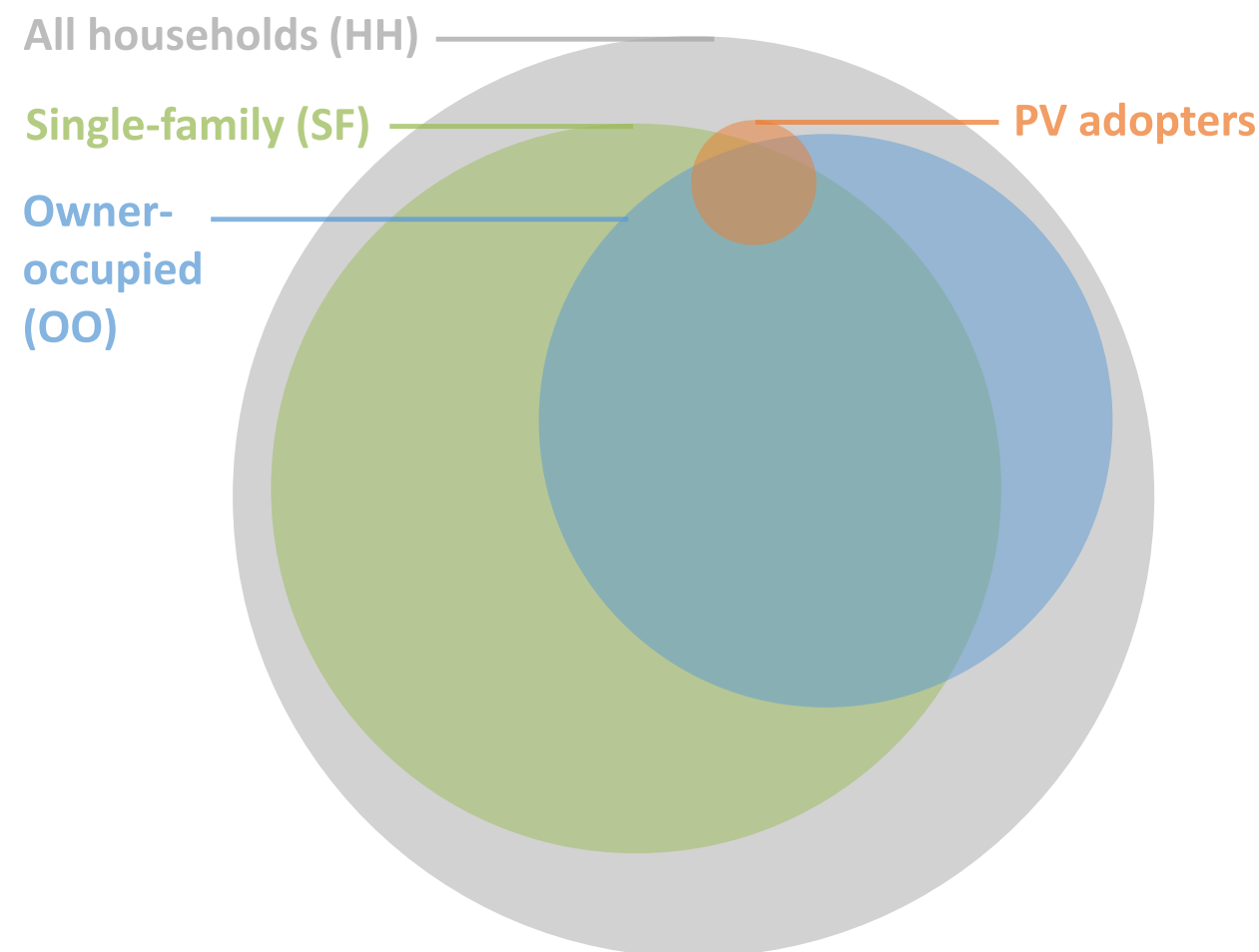
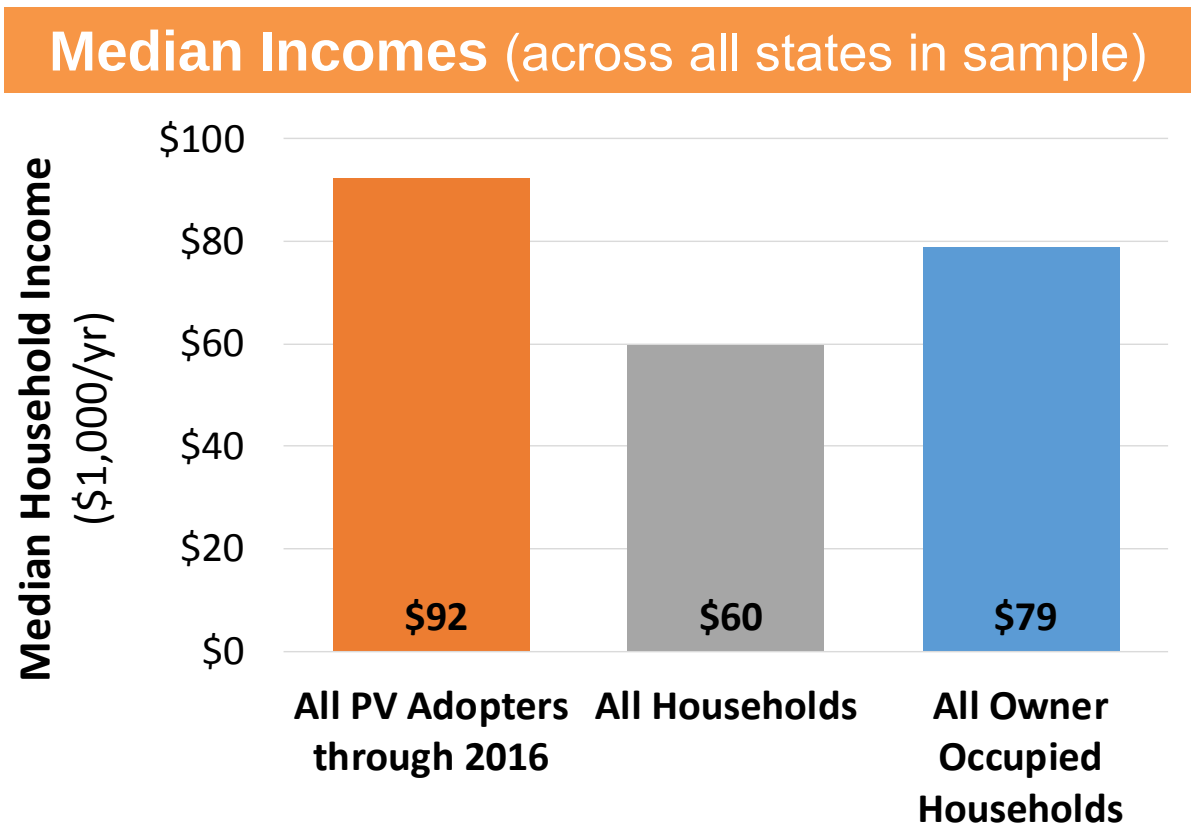


Diagram not drawn to scale

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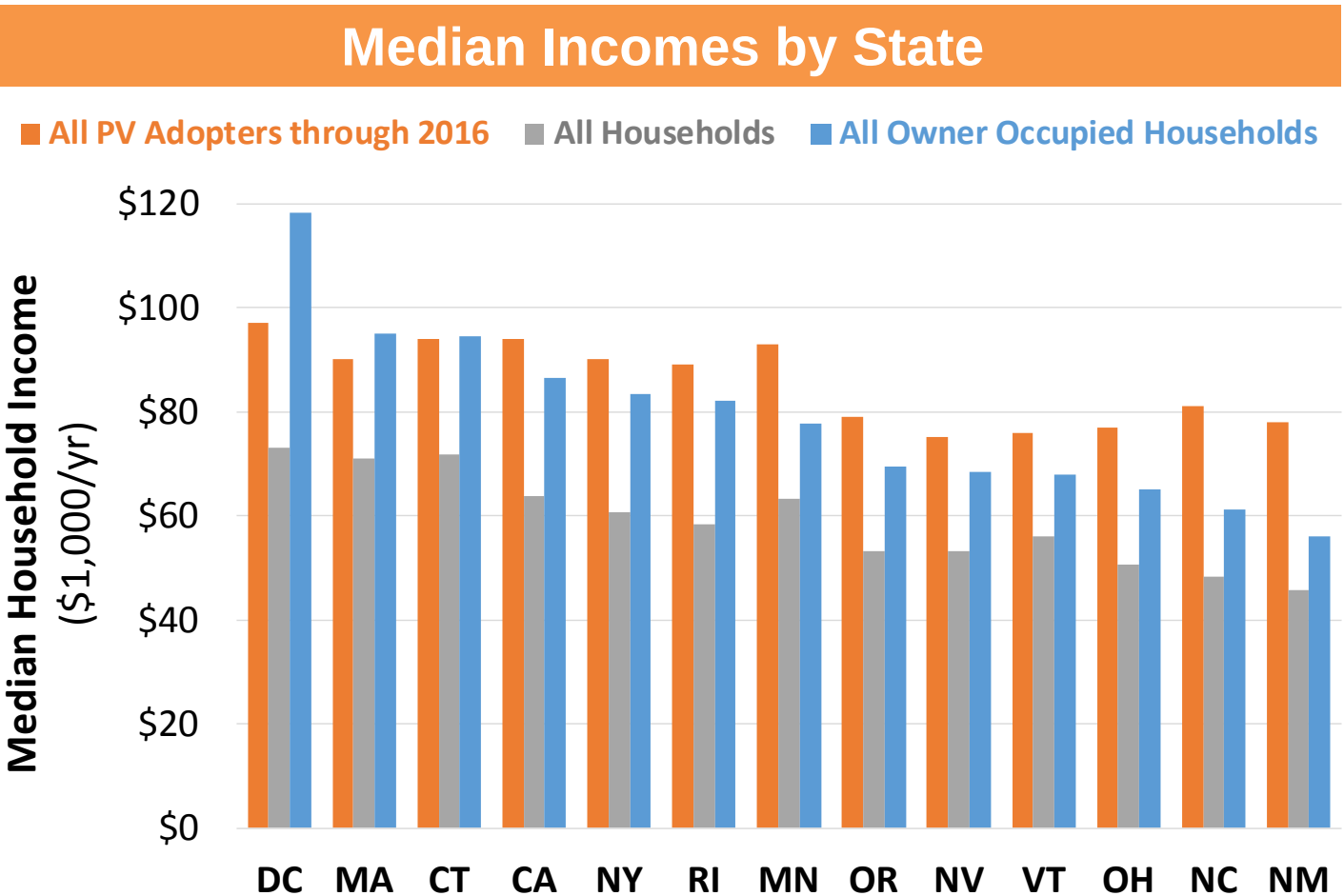
The median income of all PV adopters is notably higher than other HHs, but difference is much smaller when compared to just OO-HHs



Notes: Multi-state median incomes are calculated as a weighted average of each individual state median, weighted based on the relevant population (i.e., the population of PV adopters, all households, or all owner-occupied households).

- Median income of all PV adopters in the sample is \$32k (54%) higher than all HH
- But more than half of that difference is associated with home ownership
 - Home ownership rates much higher for HHs above state median income (77%, on average) than below (44%); see slide 31 in appendix for additional details
 - Standard “split incentive” barrier endemic to distributed energy resources generally, including energy efficiency
- Median income of PV adopters is \$13k (17%) higher than that of all OO-HH
- Gap is amplified by the concentration of PV adopters in relatively high-income states
 - Pulls PV median upward, while medians for all HHs and OO-HHs reflect distribution of broader population

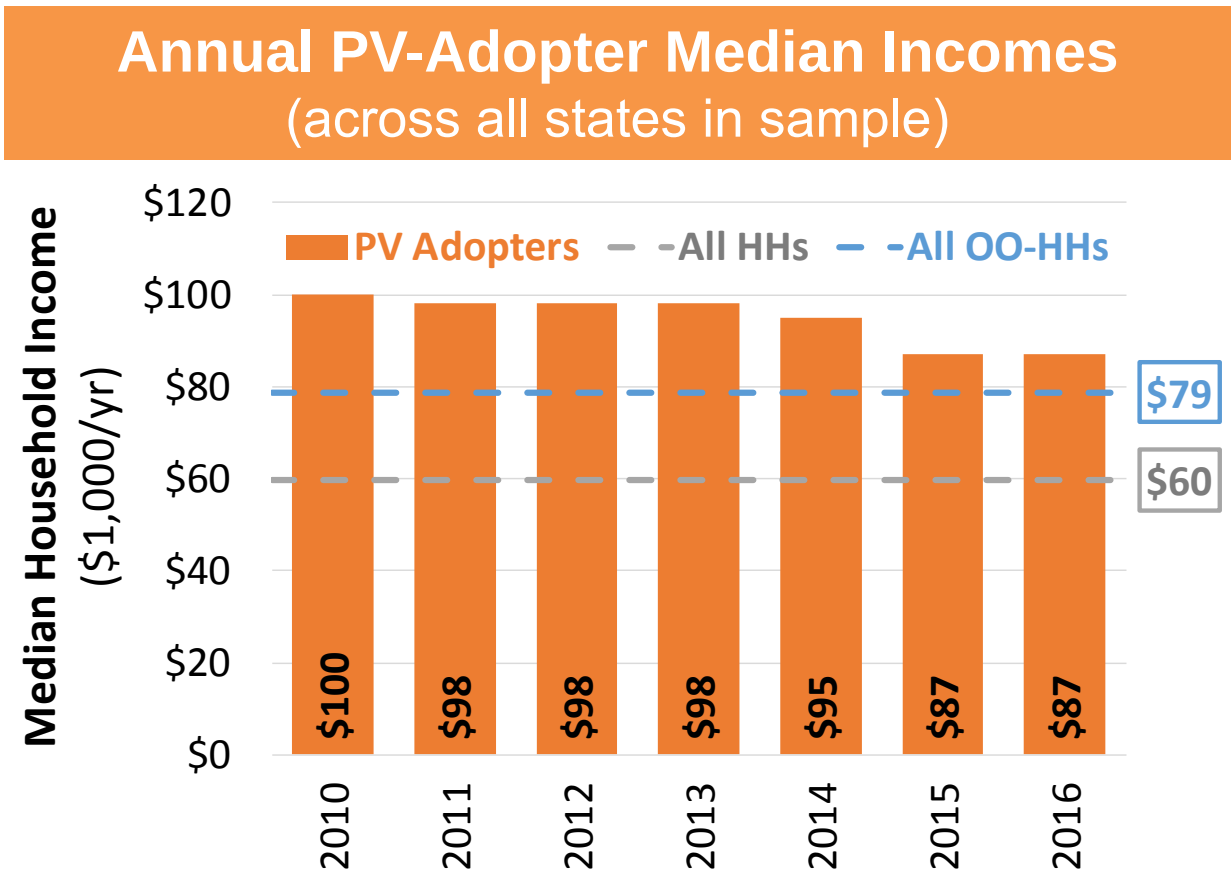
Similar trends exhibited in most states, with greatest PV-adopter income disparities in states with relatively low statewide incomes



Notes: States ordered from highest to lowest based on median income of all owner-occupied households.

- PV-adopter median incomes across the 13 states in the sample are ~\$20k-\$30k (30%-70%) higher than for all HH
- Differences consistently much smaller when comparing to just OO-HH
- Gap between PV adopters and all OO-HHs vary with overall statewide income levels
 - Gap is smaller for high-income states—and is even inverted for the three states (DC, MA, CT) with the highest statewide incomes
 - In states with relatively low statewide incomes, PV-adopter incomes are also lower, but not to the same extent as the overall population of OO-HHs

PV-adopter median incomes converging toward broader population

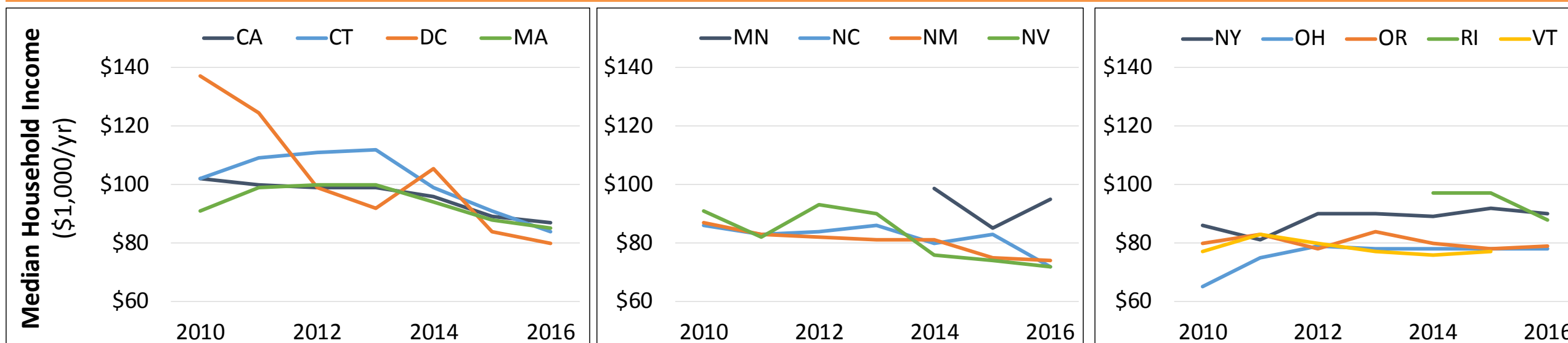


Notes: See earlier slide for method used to calculate multi-state median incomes. Income levels for PV adopters in each year are based on estimated current income of those HHs, not the income in the year of installation. Accordingly, the reference incomes shown for all HHs and all OO-HHs are fixed over time based on the latest Census data.

- Prior results focused on all PV adopters cumulatively, but annual trends show that PV-adopter median incomes have been trending downward in recent years
- PV adopters converging toward median income of all OO-HHs: PV-adopter median income 10% higher than all OO-HHs in 2016 (\$87k vs. \$79k), compared to 27% higher in 2010
- Figure here focuses on period since 2010; later slide contrasts these trends with the earlier era
- Aggregate PV-adopter median income across all states is driven heavily by CA, but most states show similar downward trend

Most states show a decline in PV-adopter median incomes over time

Annual PV-Adopter Median Income by State

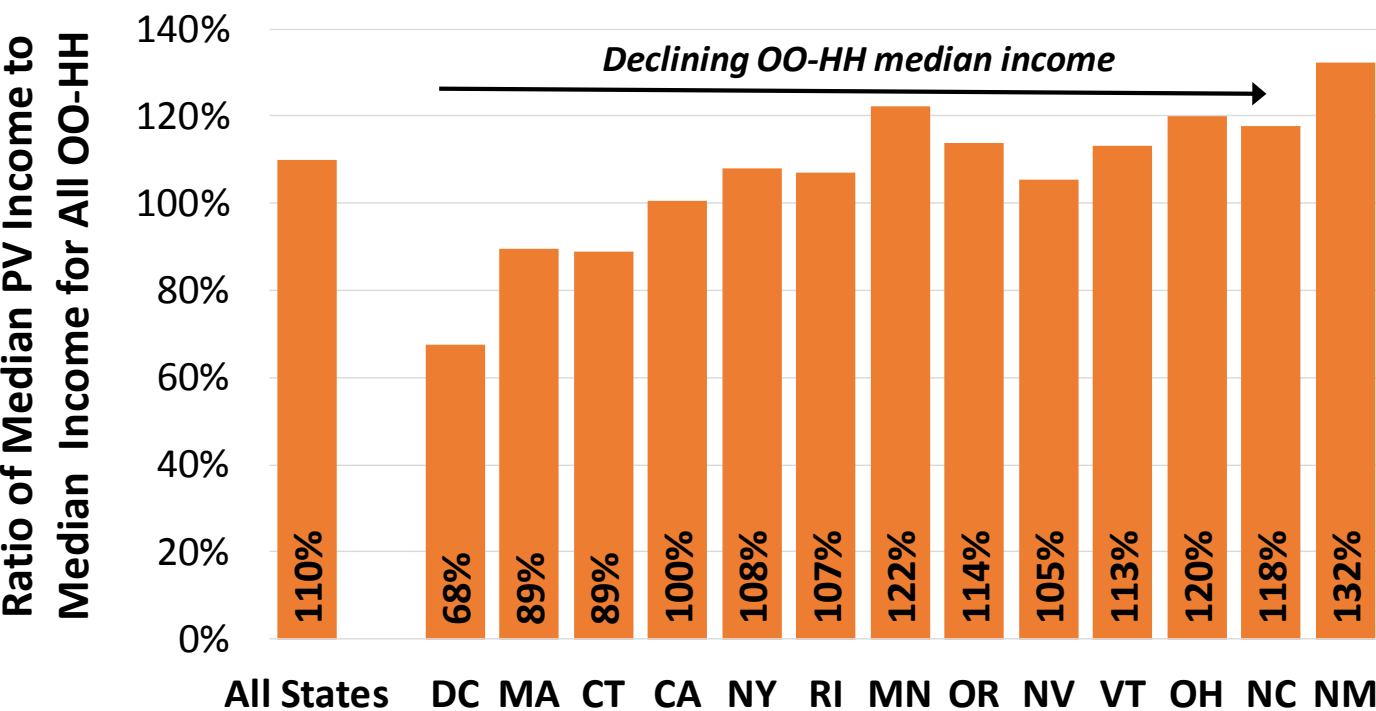


Notes: States divided among figures alphabetically, simply to aid visual comprehension. For several states (MN, RI, VT), sufficient sample sizes are available for only a portion of the time period shown. Income levels for PV adopters in each year are based on estimated current income of those HHs, not the income in the year of installation.

- Notwithstanding some inter-annual volatility, median PV-adopter incomes in most states have generally been trending downward in recent years
- Some states (NY, OH, OR, VT) show little change or even slight increases in PV-adopter incomes over the period shown, but these also tend to be states with relatively low PV incomes

2016 PV-adopter median incomes in most states were greater than other OO-HHs, though four states have reached “income parity”

PV-Adopter Median Incomes Relative to Median Income of all OO-HHs (2016 PV Adopters)

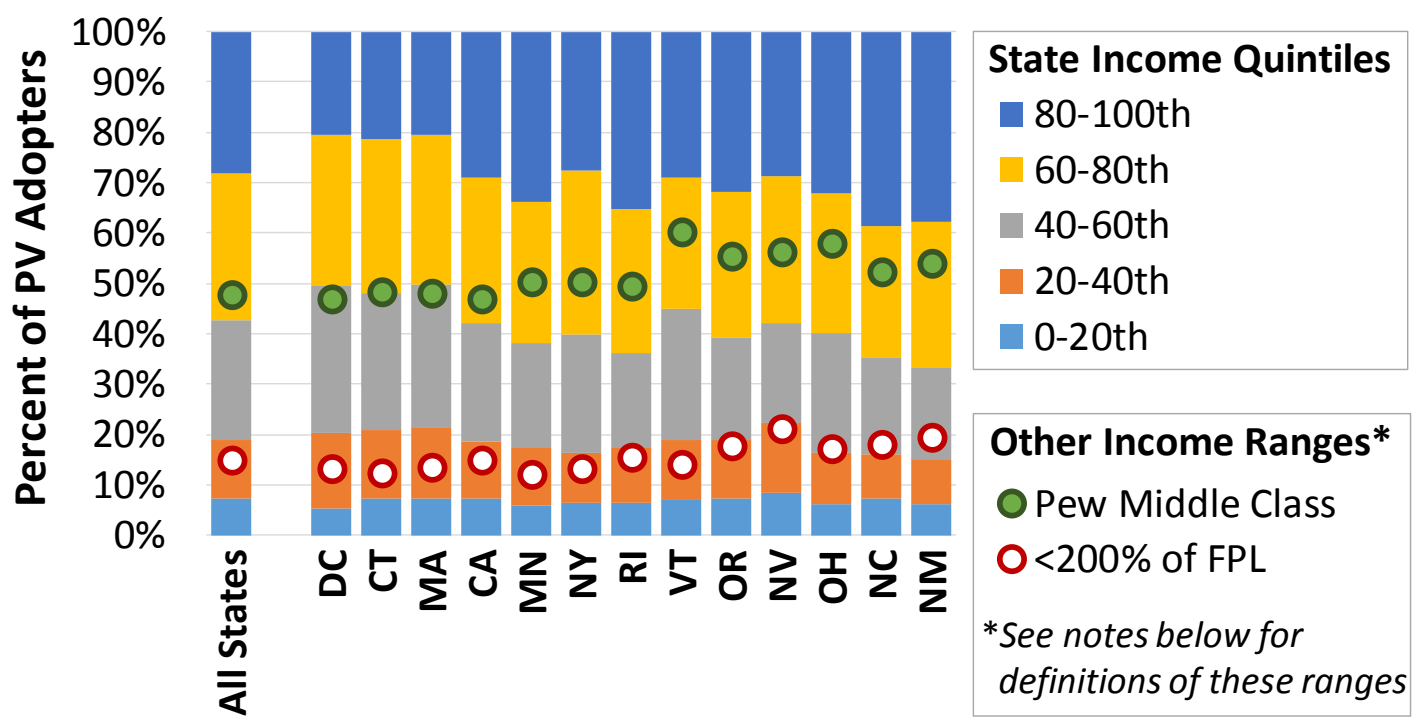


Notes: States ordered from left to right according to declining median income of all OO-HHs (see slide 13 for those values). For VT, we use data for 2015 PV adopters, owing to the limited sample size for 2016.

- Across the 13 states in the sample, PV-adopter median incomes in 2016 ranged from 68%-132% of the median income for all OO-HHs
- Four states (DC, MA, CT, CA) have reached “income parity”, with PV adopter median incomes equal to or below other OO-HHs
- For reasons discussed previously, variation in results across states is strongly associated with the overall median income of OO-HHs
 - Lower ratio of median income in states with higher overall incomes for OO-HHs

Even if often under-represented, “moderate-income” households nevertheless constitute a sizeable share of cumulative PV adopters

Income Distribution of All PV Adopters through 2016

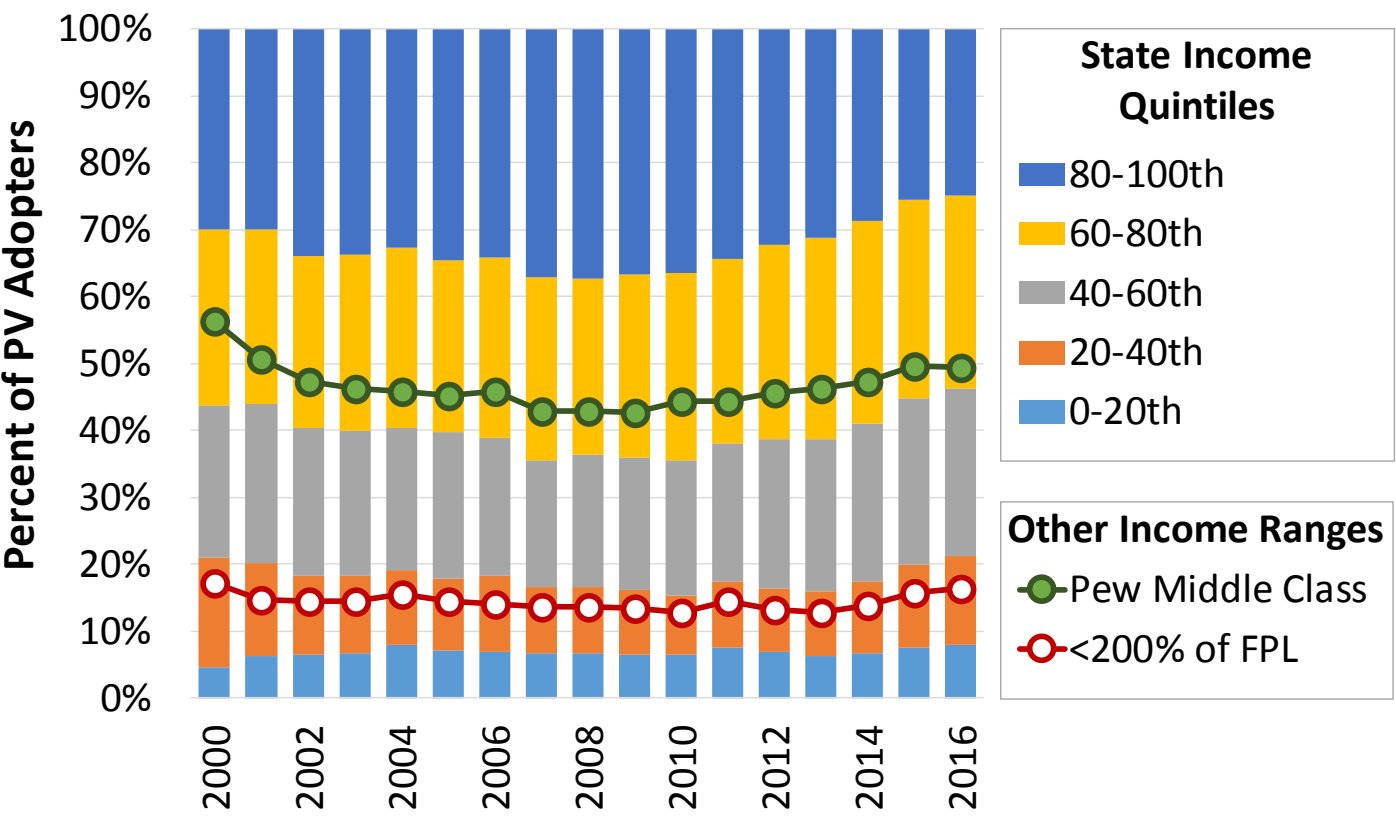


Notes: States ordered left to right according to declining median income of all OO-HHs. Income quintiles based on all HHs in each state; the distribution for “All States” uses the quintiles for each PV adopter’s respective state. See slide 33 for distributions in absolute dollar terms. The Pew Research Center defines “middle class” households as those with incomes of 67% to 200% of the U.S. median household income (\$53,889 in 2016). The Federal Poverty Level (FPL) was equal to \$20,420 for a 3-person household in 2016.

- 43% of all PV adopters in the sample (33%-50% across individual states) fall within the lower 3 income quintiles
- 48% of all PV adopters (47%-60% across individual states) fall within Pew’s definition of “middle class” (see notes)
- Even low-income groups are represented, with 15% of all PV adopters below 200% of the Federal Poverty Level: a common benchmark used in low-income programs
 - Though some questions exist about income estimates at the lower end, discussed later
- Cross-state differences largely driven by more-general income differences across states (slide 32 shows this more clearly)

PV adoption has generally been trending towards more-moderate income HHs in recent years, in contrast to earlier trend

Income Distribution of PV Adopters by Install Year



Notes: The distributions are based on all states in the sample. Income distribution for PV adopters in each year is based on estimated current income of those HHs, not the income in the year of installation.

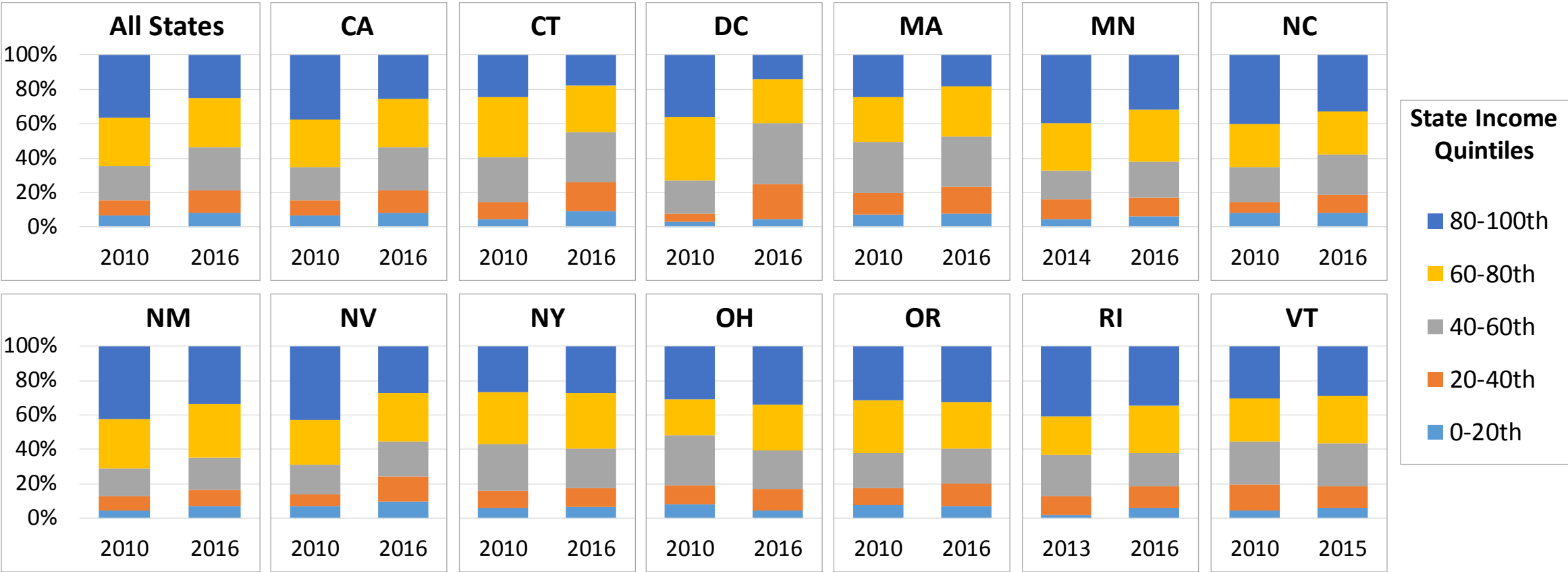
- **Prior to 2010:** PV adoption becomes increasingly skewed toward higher income households
 - Early adopters, nascent markets in most states (mostly CA)
- **Since 2010:** Share of adopters from more-moderate incomes (<60th percentile) steadily increasing
 - Rapid cost declines, growth of TPO, maturing markets, programmatic initiatives and business models targeting LMI

While the aggregate temporal trend across all states is heavily driven by CA, most other states show similar trends since 2010.

Most states also trending toward more-moderate income adopters

With some exceptions, depending on the set of income quintiles considered

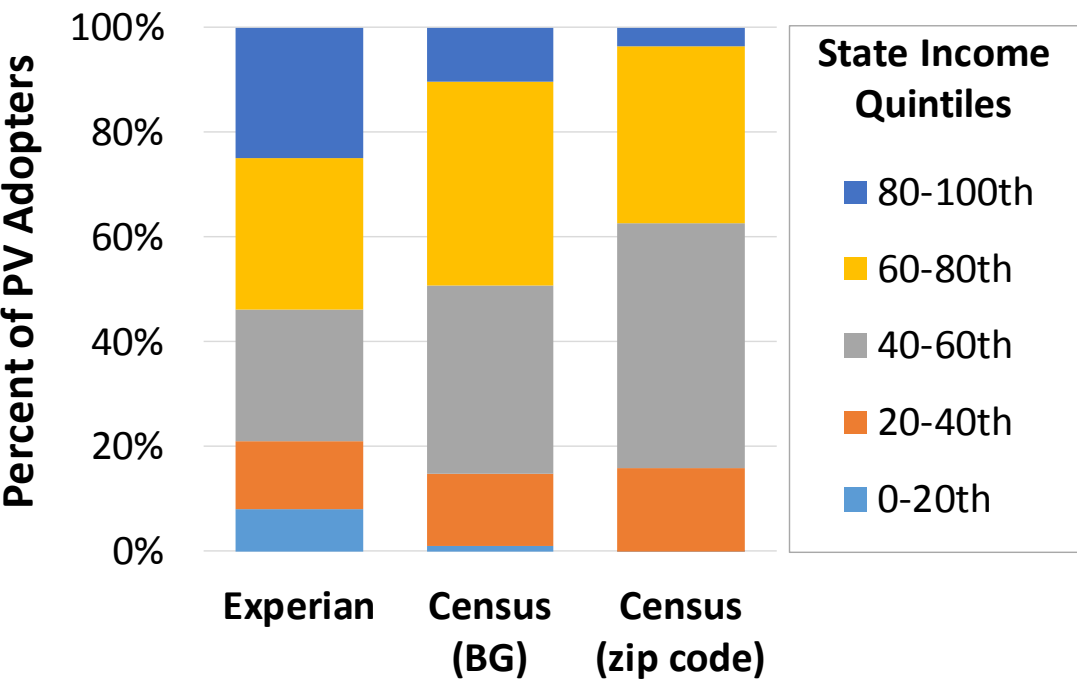
Income Distribution of 2010 vs. 2016 PV Adopters (or closest available years)



Notes: A narrower range of years is shown for several states (MN, RI, VT) due to limited or unavailable data for 2010 or 2016. Income distributions for PV adopters in each year are based on estimated current income of those HHs, not the income in the year of installation.

Methodological Side-Bar: Using Experian HH income estimates yields materially different results than using Census BG or zip code median incomes

2016 PV Adopter Income Distributions *Comparison of three income estimates*

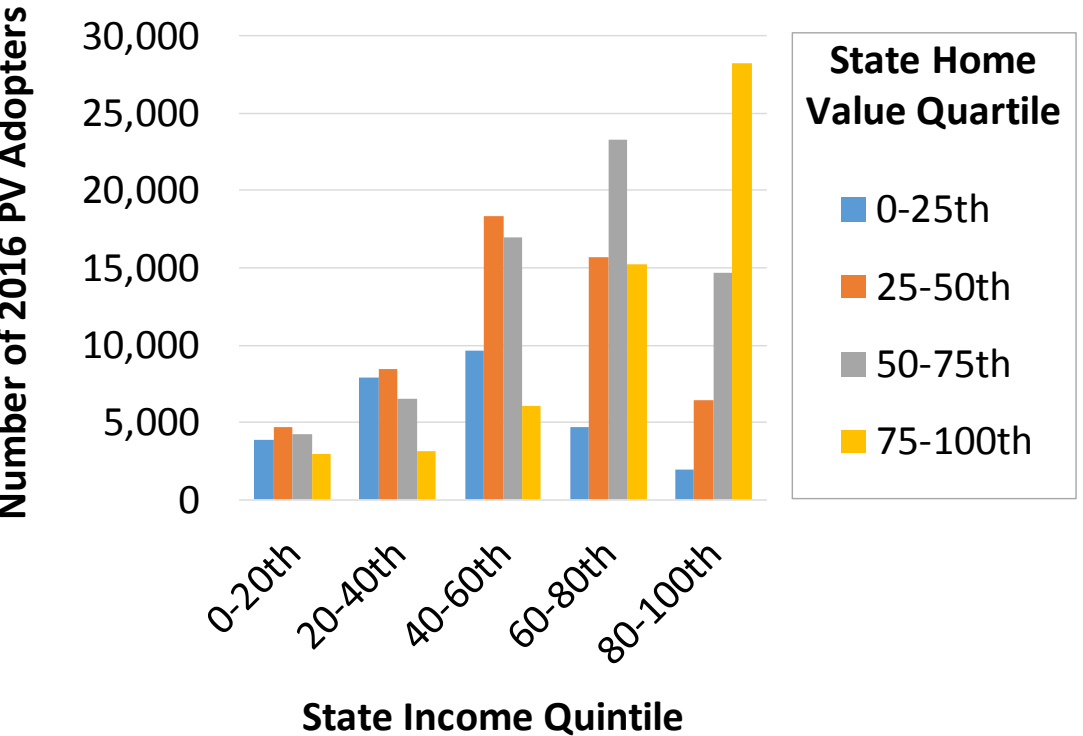


Notes: For the Census (BG) distribution, the income assigned to each PV system is the corresponding BG median income. For the Census (zip code) distribution, the income assigned to each PV system is the average of the BG median incomes within the corresponding zip code, weighted by the residential population in each BG.

- Prior analyses of PV-adopter income trends have often used zip-code average incomes (for want of customer street addresses) or median BG incomes (for want of HH-level income data)
 - Roughly 600 HH per BG; 3000 HH per zip code
- One of the chief innovations of the present analysis is to use HH-level income estimates for each available PV street address
- The results differ materially in two ways
 1. **Shift in the distribution toward wealthier households:** PV adopters tend to have higher incomes than other HHs in their BG and zip code
 2. **Greater representation among the “tails” of the income distribution:** Using median incomes across BGs or zip codes dampens income variability

Methodological Side-Bar: There are some questions about the accuracy of the income estimates at the lower end of the spectrum

Comparison of Income Levels vs. Home Values for 2016 PV Adopters



Notes: The home value for each PV adopter is binned according to the distribution of home values in the corresponding state (which are available as quartiles)

- For PV adopters in most income groups, home values more-or-less correspond to income
- However, for PV adopters in the lowest income quintile, the home-value distribution is flat, suggesting a relatively high share of these customers may not, in fact, be “low income”
 - One theory explored, but ultimately refuted, is that a disproportionate share of low-income PV adopters are retirees
- Data on participation in CA low-income electricity rates (see slide 34) also show a larger number of estimated low-income PV adopters than expected
- Possible explanations: (1) less-robust data available for the estimated income model for low-income HHs versus higher incomes; (2) the process of fitting income estimates to census data may skew low-income results

Estimating LMI Adoption Rates

PV Adoption Rate: *Number of PV adopters divided by total number of (applicable) HH*

- We estimate adoption rates among all HHs and among just OO-HHs, on both a cumulative and annual basis
- We assume that the income distribution of our PV-adopter sample for each state is representative of all PV adopters in the state
- We compare adoption rates for LMI households vs. overall PV adoption rates → provides a measure of whether and to what extent LMI adoption lags behind the broader market

Defining “LMI”: *Following the convention of many LMI-oriented solar programs, we classify households as LMI based on their income relative to Area Median Income (AMI)*

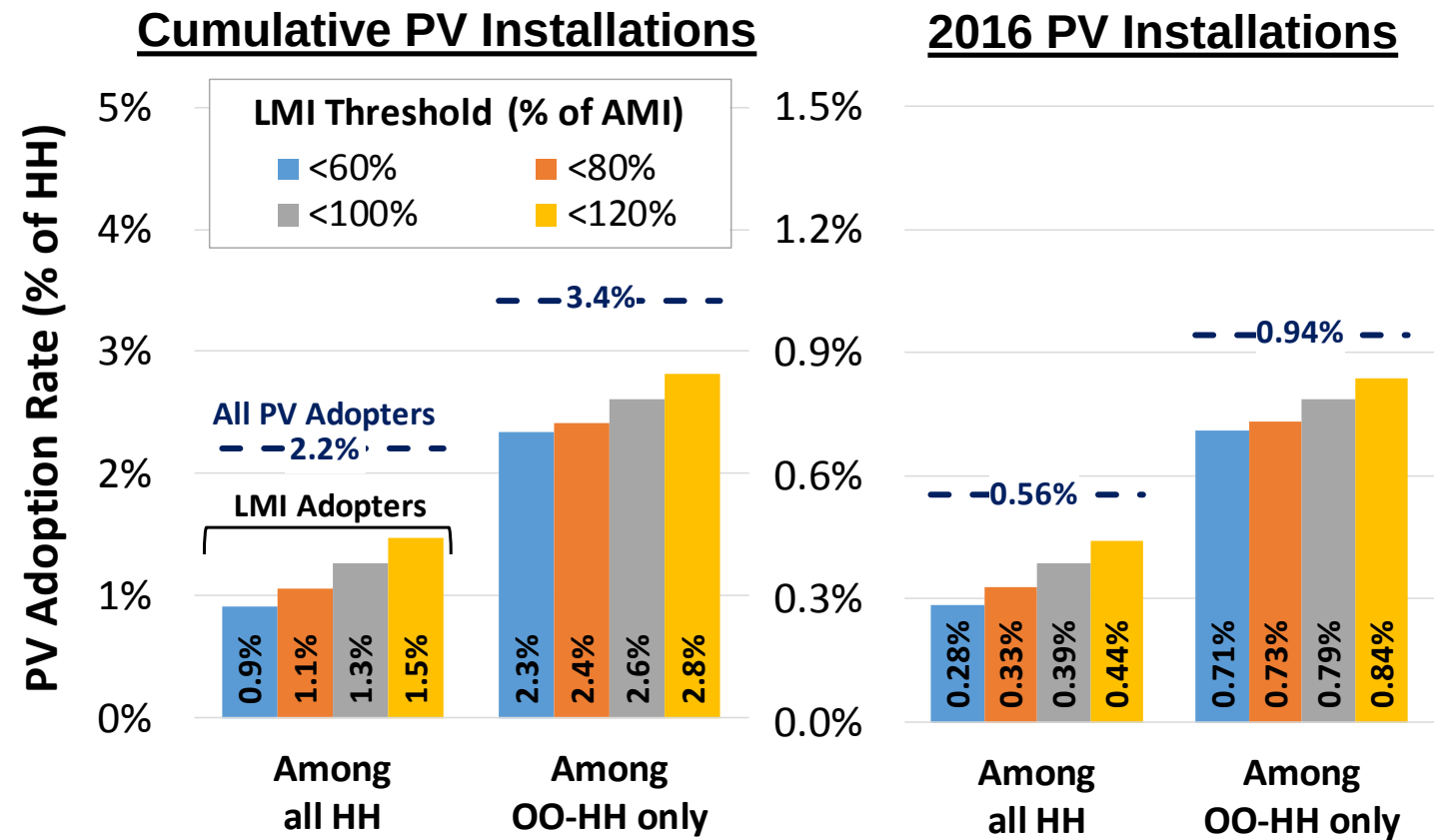
- Specific AMI thresholds vary by program (typically anywhere from 60% to 120% of AMI), depending in part on whether the focus is just on *low-income* or on *low- and moderate-income*
- Side note: Using state median incomes rather than AMI yields almost identical LMI adoption rates for most states (suggesting that PV adopters are relatively well-dispersed within each state)

PV adoption rates by LMI customers lag behind the broader market

Though the disparity is smaller when focusing just on OO-HHs and 2016 installs

PV Adoption Rates: LMI compared to All Incomes

Aggregate results across all states in the sample



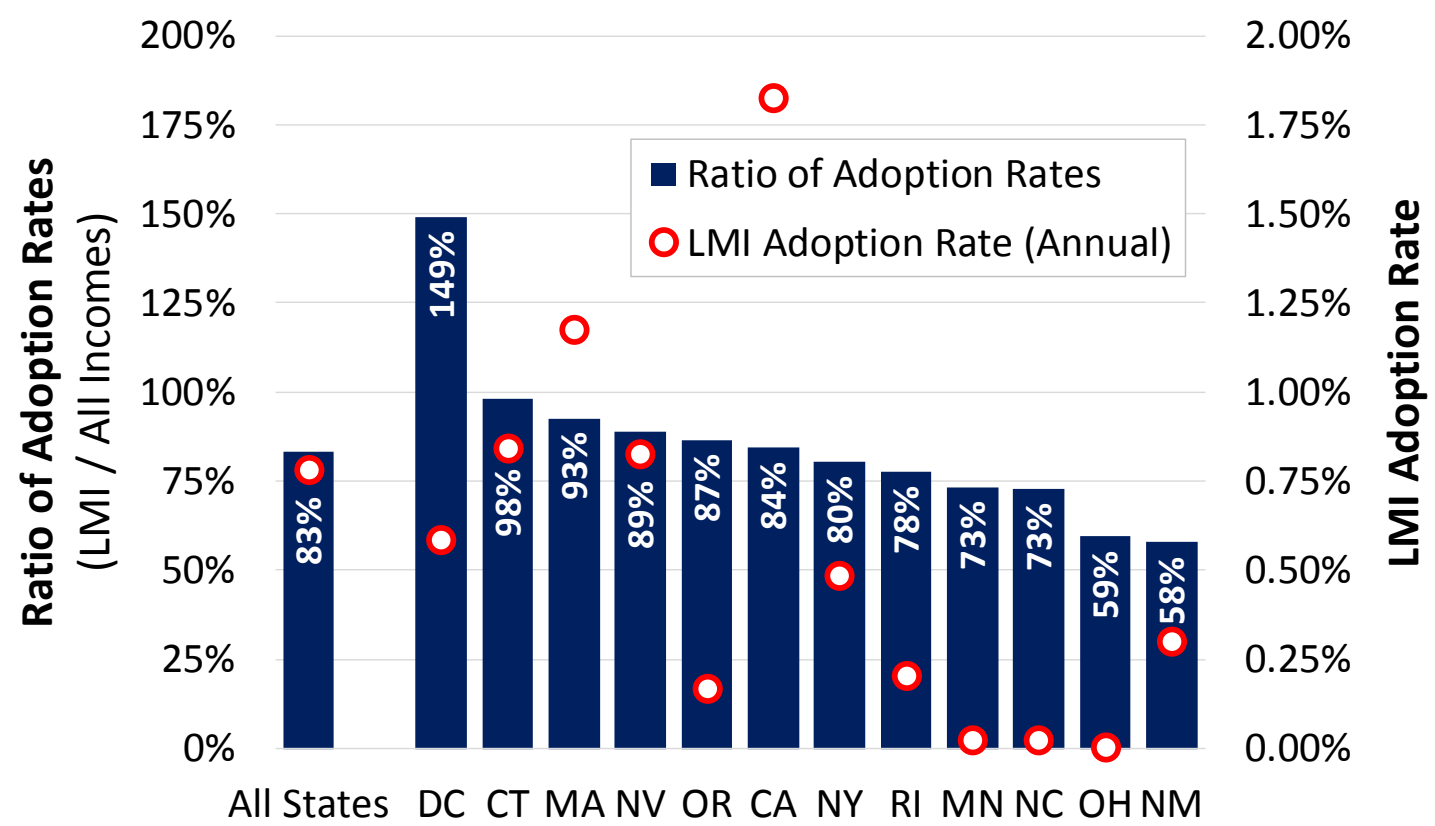
In general, results mirror and reinforce earlier comparisons of median incomes and PV-adopter income distributions

- In aggregate across all states in the sample, the LMI adoption rate is below the overall market adoption rate
- The gap is smaller for more-expansive LMI definitions (120% vs. 60% of AMI)
- The gap is also smaller, in relative terms, when focused specifically on adoption among OO-HHs (given lower rates of home-ownership among LMI customers)
- The gap is smaller among 2016 installs, as PV adoption shifts towards more-moderate income HHs, but still persists

LMI adoption in each state also tends to lag the broader market

DC is an exception, in part because of how the MSA is defined

Ratio of LMI to Overall Statewide Adoption Rates
(2016 PV installs, OO-HHs only, LMI defined as $\leq 100\%$ of AMI)

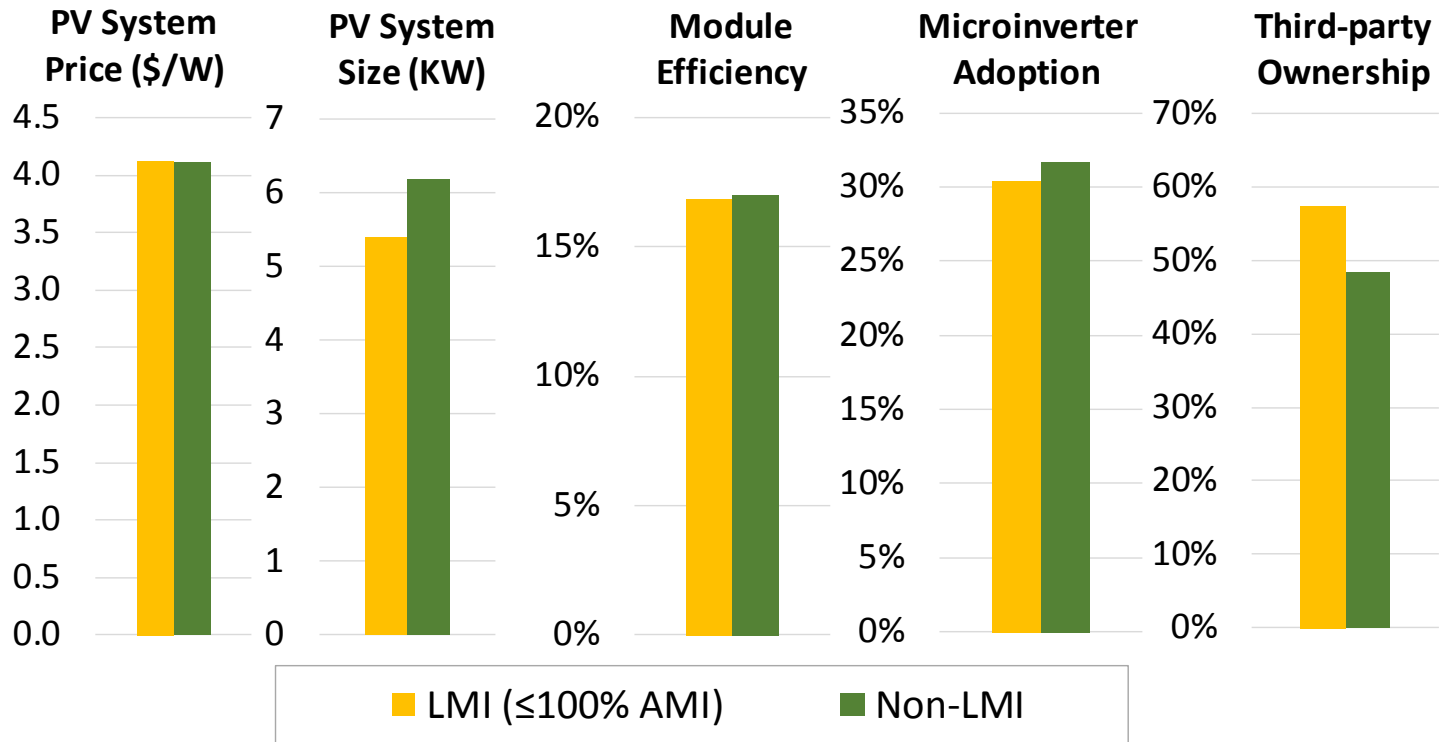


- Annual LMI adoption rates vary widely across states, from $<0.01\%$ to 1.8% of OO-HHs in 2016, using the particular LMI definition here (see slide 35 for cumulative LMI adoption rates)
- Generally range from 70-90% of the overall state adoption rate, though LMI rate is near or above broader market rate in several states (DC, CT, MA)
- In general, less lag in states with higher overall incomes, as LMI HHs in these states have higher absolute income levels
- This dynamic further accentuated in DC, as it is part of a larger MSA that includes high-income areas of VA and MD, further raising the absolute income threshold for LMI

LMI PV systems tend to be somewhat smaller, more likely to be TPO

But few apparent differences in system price, module efficiency, or microinverter use

PV System Characteristics for LMI vs. Non-LMI (2016 PV Installations, LMI defined as $\leq 100\%$ of AMI)



- **Median system size: ~5.4 kW** for LMI customers ($\leq 100\%$ of AMI) vs. **6.2 kW** for non-LMI customers

- Larger systems cost more, and lower-income HHs are more constrained financially; LMI HHs may also have less energy consumption to offset and smaller roofs

- **Third-party ownership (TPO): 57%** of LMI customers vs. **48%** for non-LMI

- LMI HHs may have greater cash constraints, less access to other financing options, and less ability to directly monetize tax benefits

Notes: Figure is based on all systems in the analysis sample installed in 2016 for which the relevant data (e.g., module efficiency, inverter type, system ownership type) are available.

Outline

- Overview and Background
- Data
- Results
 - Median incomes of PV adopters vs. broader population
 - Income distribution of PV adopters
 - LMI adoption rates
 - LMI adopter characteristics
- **Conclusions**
- Appendix

Conclusions

- **The choice of data and metrics clearly matter:** For example, results and associated take-away messages can differ significantly depending on use HH-level data vs. Census BG medians or zip-code average incomes; and depending on whether PV adopters are compared to all HH or just OO-HHs
- **Home-ownership is a key driver for differences in PV adoption among income groups:** Reinforces importance of business models and programs aimed at renters
- **PV-adopter incomes are diverse:** While PV adopters as a whole are higher-income than the population at large, it should not be overlooked that “moderate-income” or “middle-class” households are already a significant beneficiary of existing solar markets
- **The income profile of residential PV adopters is dynamic and evolving:** Suggests some value in periodically re-assessing PV-adopter income trends, and raises questions about the underlying drivers for recent trends and about how those trends may evolve going forward
- **Local and regional factors impact the income characteristics of PV adopters:** Though much of the cross-state variation in PV income trends is a function of more-general statewide income differences, other market and policy drivers likely play a role as well, and could become more significant in the years ahead

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- Conclusions
- **Appendix**

Analysis Sample: Data Sources

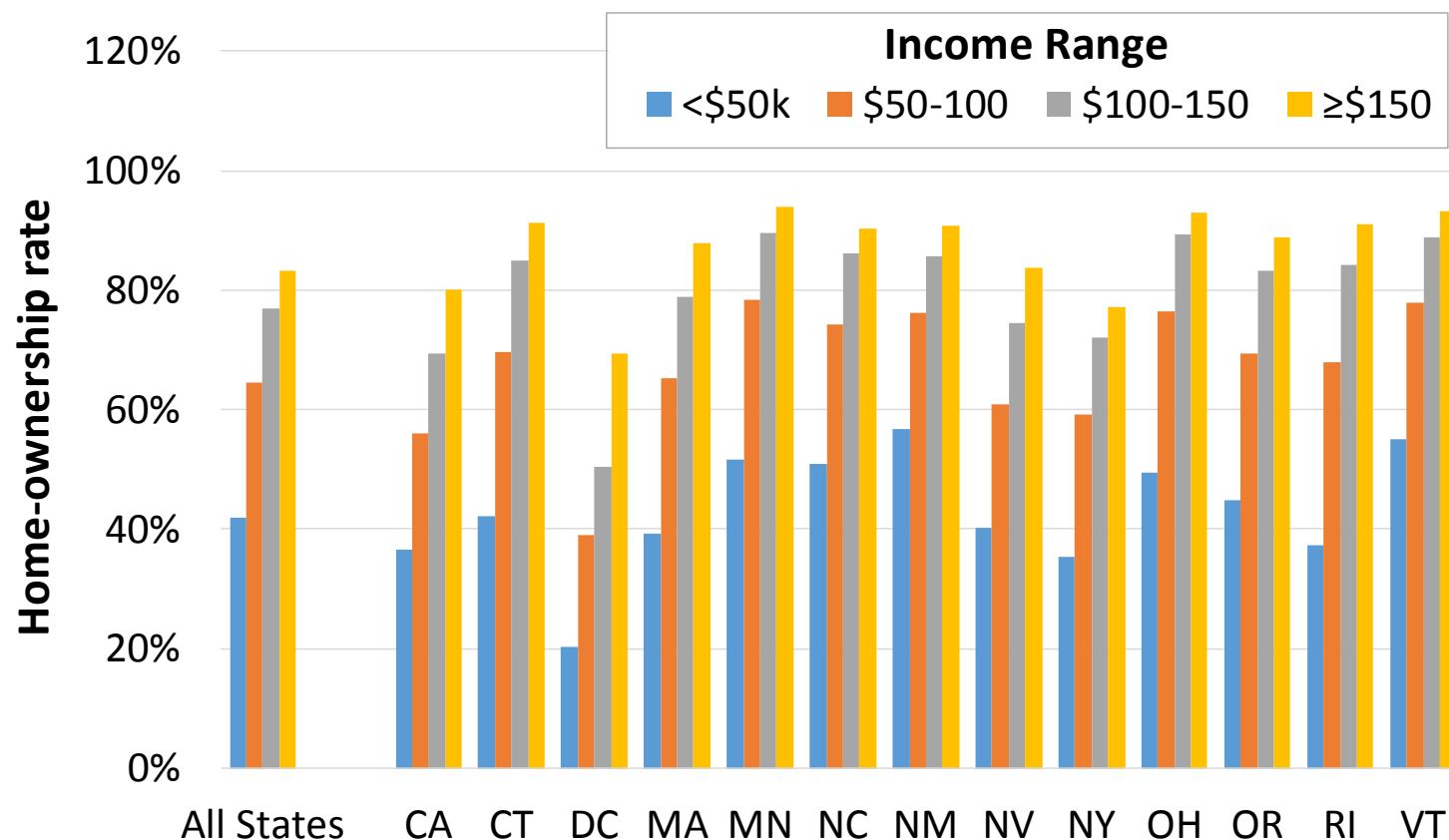
State	Data Sources	Analysis Sample	Market Coverage	Notes
CA	CPUC: Currently Interconnected Dataset, CSI Working Dataset, Self-Generation Incentive Program CEC: New Solar Homes Partnership, Emerging Renewables Program Imperial Irrig. District: All net-metered systems, California Solar Initiative	595,892	92%	Projects matched across overlapping datasets to avoid double-counting
CT	CT Green Bank: Various incentive programs	18,989	82%	
DC	DC PSC: Systems certified for RPS eligibility	2,572	94%	
MA	MA DOER: SREC I and SREC II certified systems MassCEC: Various incentive programs	61,418	95%	Projects matched across overlapping datasets to avoid double-counting
MN	MN Dept. of Commerce: Made in Minnesota program	597	26%	Only includes data on 2014-2016 installs
NC	NC Sustainable Energy Association: Applications with the NC PUC for a CPCN	4,689	93%	
NM	NM Energy, Minerals & Natural Resources Dept: State income tax credit program PNM: All interconnected systems	10,581	87%	Data from the state tax credit program includes only host-owned systems. Projects matched across overlapping datasets to avoid double-counting.
NV	NV Energy: All interconnected systems	20,150	85%	
NY	NYSERDA: Various incentive programs	47,340	64%	Market coverage relatively low because street address data unavailable for a substantial fraction of systems
OH	OH PUC: All in-state systems certified for RPS eligibility	1,765	66%	Market coverage relatively low because a substantial fraction of street addresses could not be matched with either a HH or zip+4-level income estimate
OR	Energy Trust of Oregon: Various incentive programs OR Dept. of Energy: State income tax credit programs	11,693	94%	Projects matched across overlapping datasets to avoid double-counting
RI	RI Commerce Corporation: Various incentive programs National Grid: All net-metered systems and all systems participating in RE Growth Program	1,936	97%	Projects matched across overlapping datasets to avoid double-counting
VT	VT Energy Investment Corporation: Various incentive programs	3,558	59%	PV incentives expired in 2015, thus effectively no market coverage of 2016 installations

Analysis Sample: Annual PV Adopters by State

State	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
CA	85	900	1,572	2,616	4,111	3,826	5,878	8,602	8,972	15,194	19,011	26,627	36,507	65,074	94,423	150,110	152,339
CT	0	0	0	0	0	32	87	165	269	469	475	404	597	1,285	3,139	6,693	5,374
DC	0	0	0	0	0	1	2	3	5	89	178	178	207	309	362	615	624
MA	1	1	0	50	98	60	197	181	319	686	545	1,093	2,907	4,804	8,970	20,295	21,215
MN	0	1	0	0	1	0	1	1	0	0	0	0	0	0	114	189	290
NC	0	0	0	0	0	3	13	20	40	102	179	350	444	435	846	1,274	991
NM	1	4	6	7	11	7	60	65	152	382	905	1,086	1,162	1,203	1,197	1,733	2,610
NV	0	0	0	0	8	58	72	92	82	166	279	127	55	235	1,410	14,587	2,979
NY	0	0	0	37	84	86	188	326	360	669	684	699	1,563	2,271	5,762	15,650	18,964
OH	0	0	1	2	4	5	9	16	27	65	137	285	240	234	248	293	199
OR	23	46	31	84	140	96	149	220	245	456	1,104	1,322	1,342	986	1,307	2,006	2,127
RI	0	0	0	0	0	0	0	1	2	1	3	0	35	54	86	339	1,415
VT	0	0	0	1	63	36	54	61	85	147	177	377	473	807	931	332	15
Total	110	952	1,610	2,797	4,520	4,210	6,710	9,753	10,558	18,426	23,677	32,548	45,532	77,697	118,795	214,116	209,142

Home-Ownership Rates for All Households

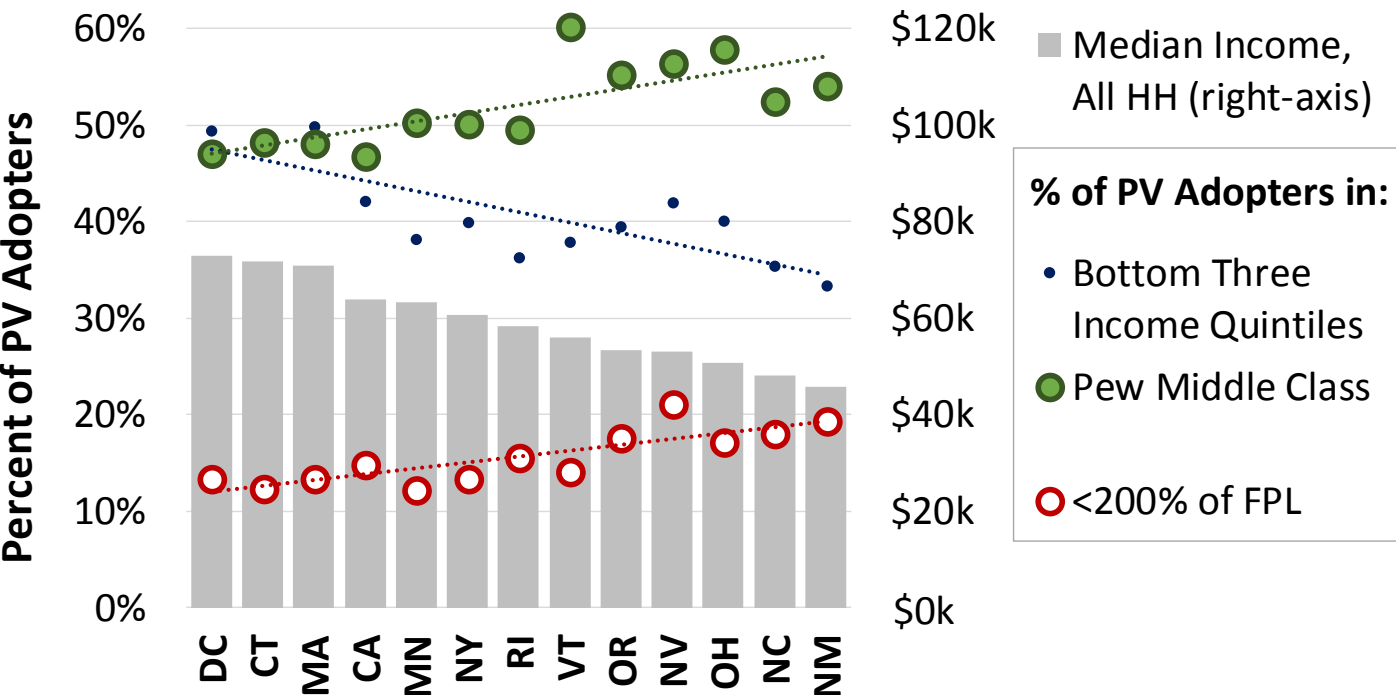
Home-Ownership Rate by Income Group
(All households, not specific to PV customers)



- The figure presented here provides further detail illustrating lower rates of home ownership for lower income households
 - Home-ownership rates are roughly double for HHs above \$150k (83% across all 13 states) than for those below \$50k (42%)
- As discussed throughout the report, higher income groups represent a disproportionate share of residential rooftop PV adopters, and have higher adoption rates, in large part as a result of differences in home-ownership rates across income groups

Differences in PV-adopter incomes across states is partly a function of more-general differences in statewide incomes

Comparison of PV-Adopter Income Statistics with Each State's Median HH Income

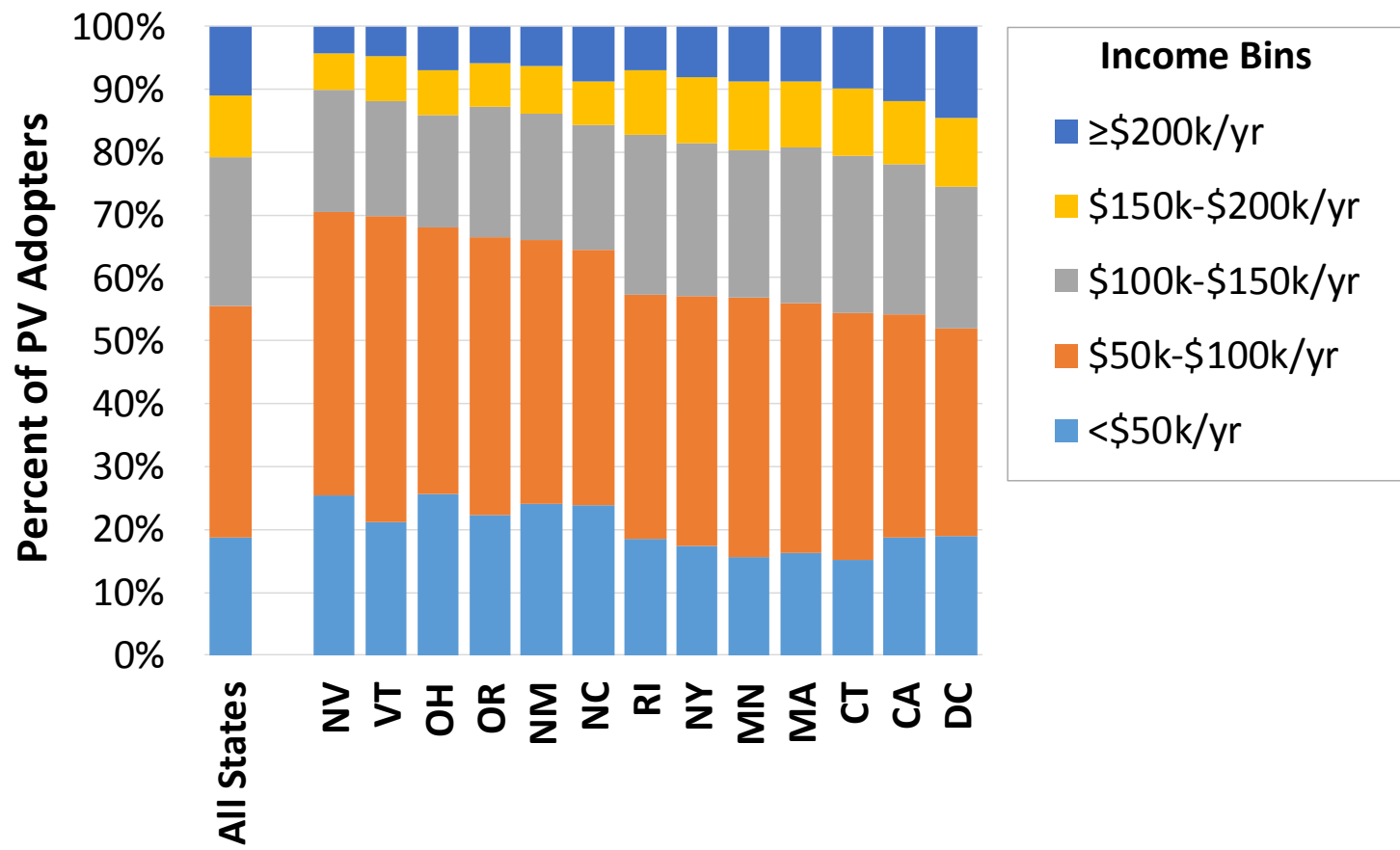


Notes: States ordered from highest to lowest based on median income of all households. The trend-lines included in the figure are intended to illustrate the general direction of the trend, but the specific slopes of those lines do not have any technical significance given that the x-axis is non-numeric.

- In states with relatively high incomes:
 - Income quintiles shifted upward; thus PV more-accessible to HHs in the bottom three quintiles
 - Smaller fraction of population is <200% of FPL and in Pew middle class; fraction of PV adopters in those groups thus also smaller
- Converse is true for states with lower overall income levels
- More of a “mathematical” phenomenon than an empirical one
- Other cross-state differences in PV-adopter income trends (as suggested by deviations from the trend-lines) may be driven by policy and market factors

PV-Adopter Income Distribution in Terms of Absolute Income Levels

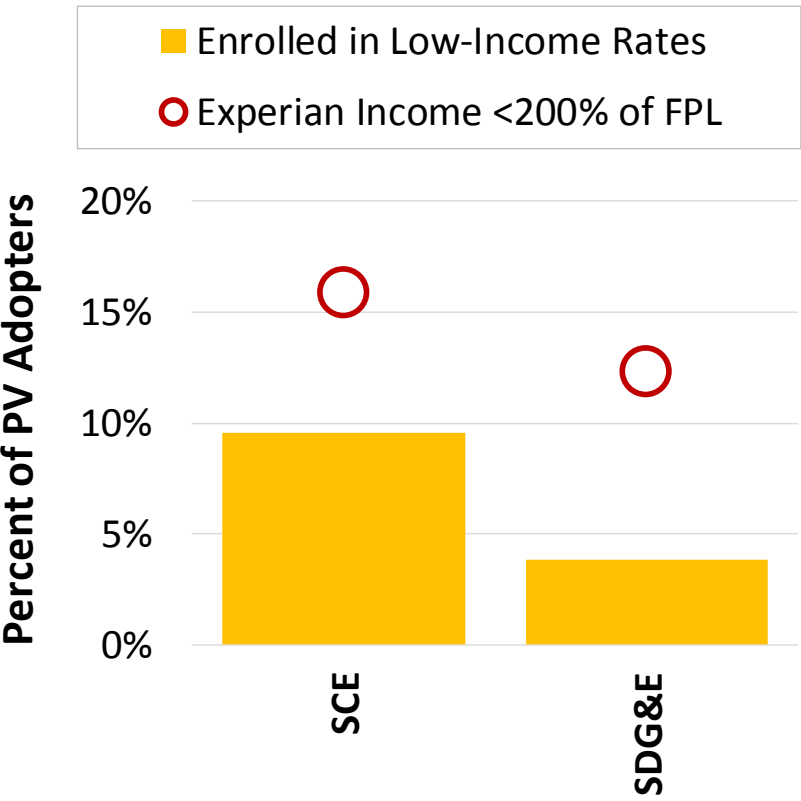
Income Distribution of PV Adopters



- This figure supplements the income distribution presented earlier, which uses state income quintiles
- Reinforces the same basic conclusion that “moderate-income” households comprise a sizeable share of PV adopters
 - 55% of all PV adopters in the sample have HH income <\$100k (~50-70% across the individual states)
- Cross-state differences highly correlate to overall statewide income levels
 - E.g., greater share of PV adopters <\$100k in states with relatively low statewide income (see previous slide), given the greater share of the overall population below that income level

Benchmarking Experian Income Estimates against PV-Customer Enrollment in Low-Income Rates for California IOUs

Experian Data vs. Enrollment in Low-Income Rates

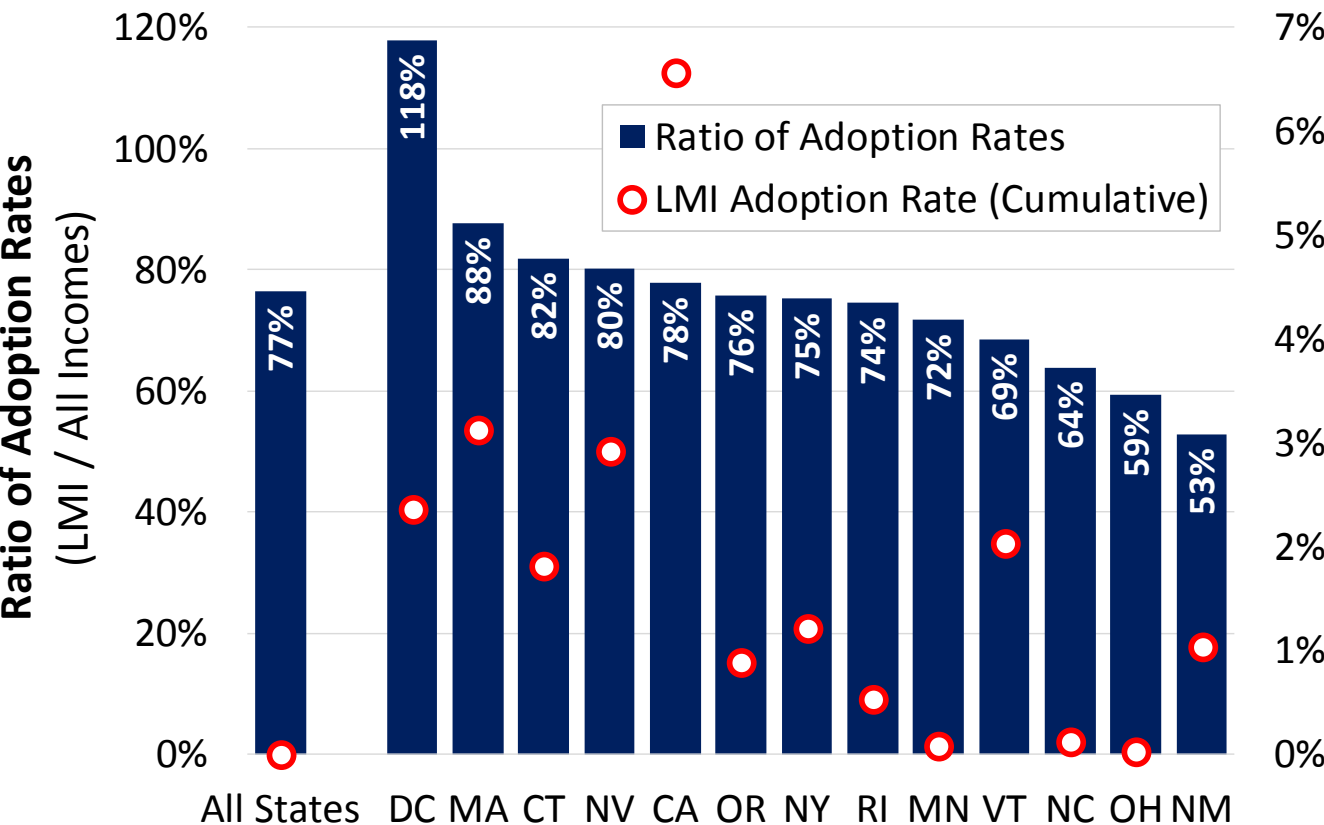


- California’s IOUs offer low-income electricity rates; eligibility is based on HH income <200% of the FPL
- LBNL receives data from the CPUC on the retail electricity tariff in which each PV customer is enrolled (at the time of interconnection)
 - We focus here on just SCE and SDG&E, due to issues with the rate data for PG&E
- As shown in the figure, enrollment in low-income rates by PV customers is much lower than the estimated percentage of eligible PV customers (10% vs. 16% for SCE, 4% vs. 12% for SDG&E)
 - One explanation is simply that some customers may be eligible for low-income rates but do not enroll
 - It may also indicate a larger number of estimated low-income households (with income <200% of FPL) than expected for these utilities (for reasons discussed on slide 21)

LMI adoption in each state also tends to lag the broader market

DC is an exception, in part because of how the MSA is defined

Ratio of LMI to Overall Statewide Adoption Rates (Cumulative installs, OO-HHs only, LMI defined as $\leq 100\%$ of AMI)



- LMI PV adoption rates vary widely across states, from $<0.1\%$ to 7% of OO-HHs, using the particular LMI definition here
- Generally range from 60-80% of the broader market adoption rate
- Lag in LMI adoption rates generally less acute in states with higher overall incomes
 - Consistent with earlier discussion, LMI HHs in these states have higher absolute income levels, and thus greater access to PV
- Results for DC also impacted by the fact that it is part of a larger MSA that includes high-income areas of VA and MD, further raising the LMI threshold

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Energy Affordability in Maryland

Integrating Public Health, Equity,
and Climate

February 2023



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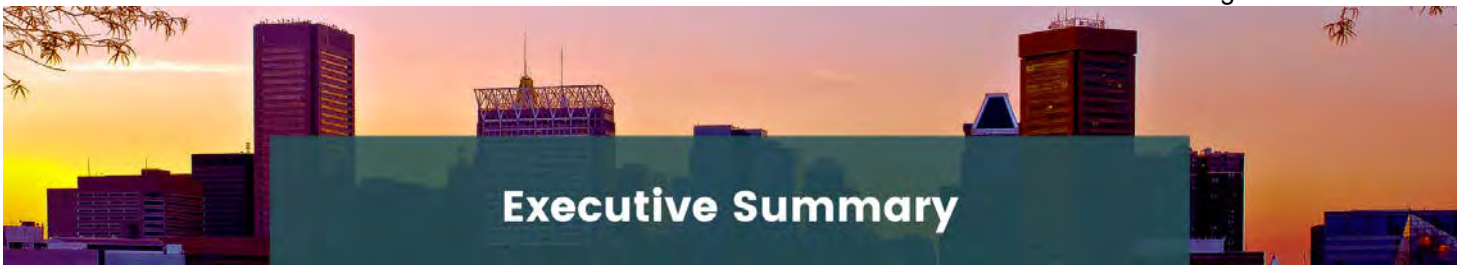
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Table of Contents

Executive Summary	6
1.0 Overview of Energy Affordability	23
1.1 Introduction	23
1.2 Maryland’s Energy Affordability Landscape	24
1.1.1 Existing State and Federal Policies	25
1.1.2 Effectiveness of Existing Policies	29
1.3 Summary	37
2.0 Energy Affordability Analysis	39
2.1 Introduction	39
2.2 Measuring Affordability	39
2.3 Energy Affordability in Baltimore City	43
2.4 Energy Cost Burdens by Income	45
2.5 Energy Cost Burden Analysis	47
2.5.1 Energy Cost Burdens by Fuel Type	49
2.5.2 Home Type and Renter Status	53
2.5.3 Race and Ethnicity	55
2.5.4 Utility Type	56
2.6 Additional Considerations for Energy Affordability	57
2.6.1 Changes in Natural Gas Prices	57
2.6.2 Homes with Very High Energy Use	58
2.7 Summary	58
3.0 Energy Use, Indoor Air Quality, and Health	59
3.1 Introduction	60
3.2 Indoor Air Quality and Health	61
3.3 Impacts of Residential Fuel Use on Indoor Air Quality and Health	66
3.3.1 Key Air Pollutants Associated with Combustion Appliances	67
3.3.2 Cooking Appliances	71
3.3.2.1 Indoor Air Pollutant Concentrations Associated With Natural Gas Cooking Appliances	73
3.3.2.2 Maryland Department of Housing and Community Development Compliance Appliance Safety Inspections	74
3.3.2.3 Health Risks and Impacts Associated with Gas Cooking Appliances	77
3.3.3 Heating Appliances	78

3.3.3.1 Indoor Air Pollutant Concentrations Associated with Heating Appliances	78
3.3.3.1.1 Gas Heating Appliances	78
3.3.3.1.2 Wood Heating Appliances	80
3.3.3.2 DHCD Data on Heating Appliances	81
3.3.3.3 Health Risks and Impacts Associated with Heating Appliances	81
3.3.3.3.1 Gas Heating Appliances	81
3.3.3.3.2 Wood Heating Appliances	82
3.4 Impacts of Residential Retrofits on Indoor Air Quality and Health	82
3.4.1 Energy Efficiency and Weatherization	83
3.4.2 Household Ventilation and Filtration	85
3.4.3 Electrification of Fossil Fuel-Powered Cooking and Heating Appliances	88
3.4.4 Healthy Homes	93
3.5 Summary	95
4.0 Impacts of Natural Gas Investment	97
4.1 Introduction	97
4.2 Direct Natural Gas Use in Maryland and Associated Emissions	98
4.3 Maryland’s STRIDE Law	102
4.3.1 The 2010 San Bruno Pipeline Explosion	102
4.3.2 Prelude to STRIDE	106
4.3.3 Features of the STRIDE Law	108
4.3.4 STRIDE Investments and Cost Recovery	110
4.3.4.1 Maryland’s Major Natural Gas Utilities	110
4.3.4.2 STRIDE Investments	111
4.3.5 STRIDE and Maryland’s Climate Law	113
4.4 Building Sector Decarbonization Implications	114
4.5 Natural Gas Distribution System Stranded Costs—Preliminary Considerations	117
4.5.1 Basis of Stranded Cost Calculations	121
4.5.2 Avoiding Stranded Costs	129
4.6 Brief Overview of the Gas Pipeline Leak, Safety, and STRIDE	130
4.6.1. National Serious Accident Data	132
4.7 Conclusions	136
5.0 Policy	136
5.1 Introduction	137
5.2 Tools for Affordability	139
5.2.1 Energy Assistance: The Current Situation	139

5.2.2 Approach to Assistance	147
5.2.2.1 Percentage of Income Payment Plan	152
5.3 Non-energy Benefits of Affordable Energy	156
5.4 Interventions and Financial Policies to Reduce Bills	161
5.4.1 Weatherization	162
5.4.2 Beneficial Electrification	166
5.4.3 Community Solar and Demand Response	167
5.4.4 Proposed Suite of Grants	170
5.4.5 Bill Impacts from Home Interventions	171
5.4.6 Financial Implications Over Time	175
5.5 Conclusions	181
Appendix	190
A.1 Energy Affordability Estimates	190
A.1.1 Methodology	190
A.1.2 Validation	192
A.1.2.1 Average Bill Comparisons	192
A.1.2.2 Total Maryland Consumption	195
A.1.2.3 OHEP Energy Usage Statistics	196
A.1.2.4 Sensitivity Analysis	197
A.1.2.5. Discussion of Potential Sources of Discrepancy in Energy Usage and Bills	198
A.1.3 Energy Estimates Summary	199
Energy Use, Indoor Air Quality, and Health Methodology	199
Acronyms and Abbreviations	201



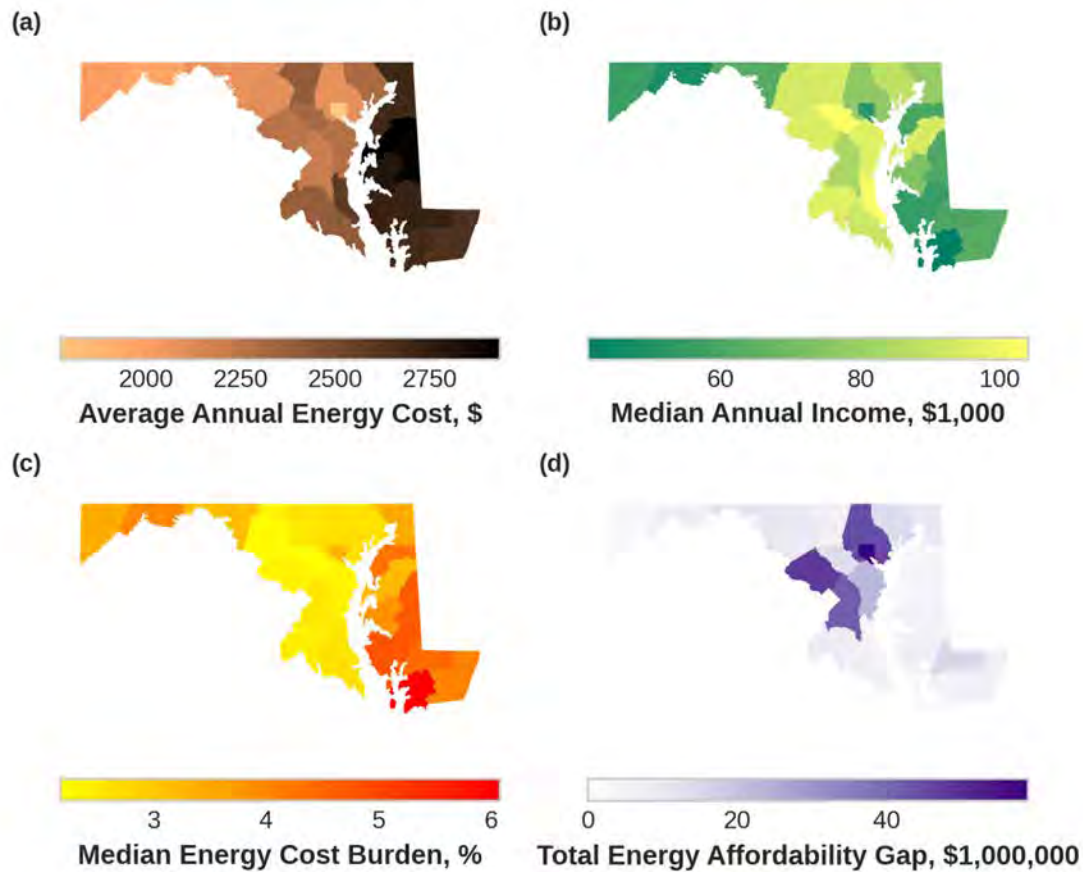
Almost 400,000 Maryland households pay more than six percent of their income on home energy bills. These high energy cost burdens often force individuals and families to make impossible choices between paying utility bills and other essentials such as rent or medicine. Over the next twenty-five years, energy costs will likely increase as utilities invest billions to replace natural gas infrastructure under the 2013 Strategic Infrastructure Development and Enhancement (STRIDE) law. Yet whether these investments will serve their useful life remains unclear, as state climate policy requires a dramatic shift away from fossil fuels, creating a serious risk of stranded costs.

In this report, The Institute for Energy and Environmental Research (IEER) and PSE Healthy Energy (PSE) outline strategies to alleviate energy cost burdens, while improving public health and achieving carbon emissions reduction goals. We find that providing near-term utility bill assistance alongside significant, long-term investments in residential building weatherization and electrification—with prioritization for low- and moderate-income (LMI) households—holds the potential to simultaneously mitigate climate and health-damaging air pollutant emissions, while alleviating energy cost burdens for those who need it most. These efforts will save money in achieving affordability for all, compared to assistance alone.

The Intertwined Challenges of Energy Affordability, Climate Change, and Public Health

Energy policy in Maryland has historically treated energy affordability, public health, and climate change as separate issues. In reality, they are deeply intertwined. Households across Maryland currently use electricity, natural gas, propane, and fuel oil to heat their homes and run their appliances, and regional patterns in fuel use affect how much people pay, which pollutants they are exposed to, and what their climate impact is. The energy system's impacts are also influenced by historic structural inequities that disproportionately harm low-income households, communities of color, urban renters, and other populations. Strategies to transition to a cleaner energy system must address the compounding burdens these households face.

Figure ES-1: a) Household energy costs, b) median household incomes, c) energy cost burdens (percent of household income), and d) total energy affordability gap for low- and moderate-income (LMI) households by county across Maryland.

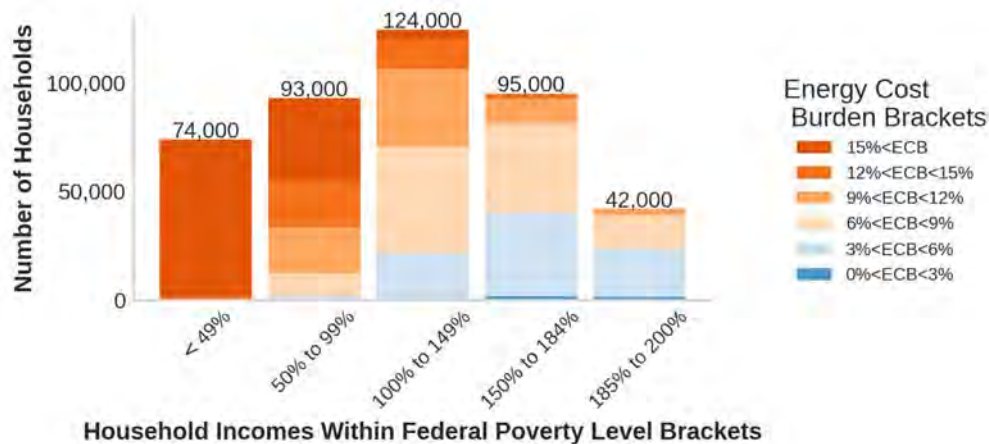


Affordability

Energy required for space and water heating, cooking, and operating lighting and other appliances is unaffordable for many Maryland households. High energy cost burdens can contribute to cascading financial challenges or a lack of energy to meet critical needs. We estimate that approximately 400,000 Maryland households (18%) pay energy bills that are considered high—exceeding six percent of their income. Between 80,000 and 90,000 low- and moderate-income households have received energy bill payment assistance in recent years. Very high energy cost burdens, sometimes exceeding 30 percent of income, are disproportionately found in low-income areas of Baltimore City with a higher density of Black households, among propane users, and in rural areas, notably on much of the Eastern Shore

and certain parts of Southern and Western Maryland. Many of these households face energy poverty and energy insecurity, which can contribute to adverse health outcomes, debt, and even homelessness. The energy affordability gap, defined as the difference between the total energy bills paid by low- and moderate-income households and the amount they can reasonably afford (six percent of income or less), is in the range of \$350 million to \$450 million per year in Maryland. About \$40 million of this gap is due to excess third-party electricity and natural gas supply charges. **Figure ES-1** maps energy cost burdens across Maryland and their relationship to energy costs and income. Energy cost burdens by income bracket for households earning up to double the federal poverty level (FPL), shown in **Figure ES-2**, can exceed 15 percent for the lowest-income households.

Figure ES-2: Number of households within federal poverty level brackets broken down by energy cost burden (ECB).



The transition to cleaner household fuels holds the potential to either alleviate or exacerbate these challenges. As households transition away from natural gas to electricity, natural gas rates will rise as fewer and fewer households pay to support the aging gas infrastructure. These rates are likely to impact low-income households, renters, and others who are unable to electrify. Without policy action (legislative and/or regulatory), energy cost burdens for low- and moderate-income households reliant on the natural gas system will rise, potentially skyrocketing after the mid-2030s. This result stems from current policies and laws that allow continued investments in the natural gas distribution system while at the same time requiring deep reductions in greenhouse gas emissions and encouraging electrification of heating.

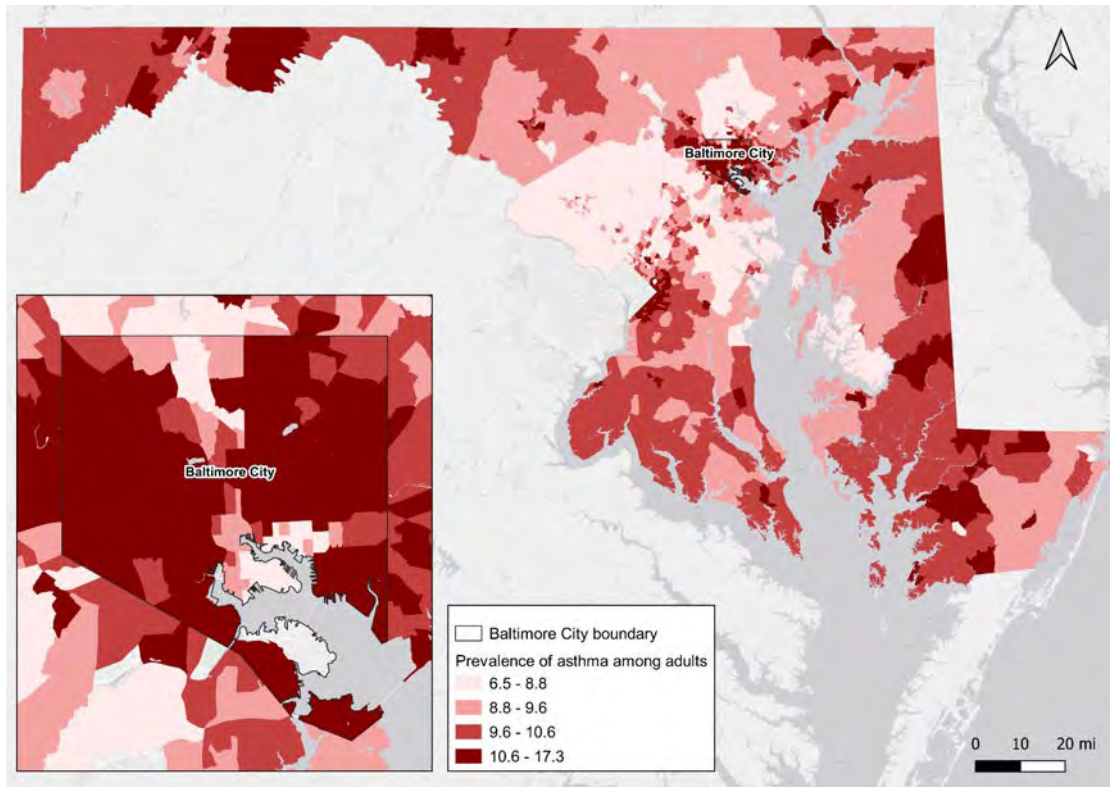
Public Health

People in the United States spend more than 80 percent of their time indoors. Given this fact, policies shaping indoor environments—such as new building construction or retrofit standards—can have significant impacts on quality of life and public health.

Residential fuel combustion for space and water heating and cooking appliances emits air pollutants such as particulate matter (PM_{2.5}), nitrogen oxides (NO_x), carbon monoxide (CO), benzene, and formaldehyde, which are associated with a variety of adverse cardiovascular and respiratory health effects, among others. Elevated indoor air concentrations of nitrogen dioxide (NO₂) and CO have been observed in Maryland households with gas stoves. Recent studies have shown that gas-based appliances can leak, even when they are not in use—contributing to hazardous air pollutant concentrations indoors.

Low-income communities and communities of color tend to be disproportionately impacted by, and are more susceptible to, environmental risk factors and adverse health outcomes. Because Maryland has a higher proportion of people of color than the national average, and Baltimore City has a higher poverty rate than the state or national average, its residents may be particularly vulnerable to degraded indoor air quality. Additionally, those with underlying respiratory or cardiovascular conditions may also be particularly vulnerable to indoor air pollution. Notably, the majority of Baltimore City neighborhoods have the highest prevalence of asthma compared to averages for the state (**Figure ES-3**).

Figure ES-3: Model-based estimate for crude prevalence (%) of current asthma among adults aged ≥ 18 years (at the census tract level), 2020, Baltimore City and Maryland. *Source: CDC (2022).*¹



Climate Change

The combustion of fossil fuels in residential buildings in Maryland produced 4.3 million metric tons of carbon dioxide (CO₂) in 2021. Methane, a powerful greenhouse gas, also leaks throughout the entire natural gas system, inclusive of production, processing, transmission, and distribution, resulting in another three million metric tons of CO₂-equivalent emissions (based on a 20-year global warming potential for methane, as required by Maryland law). The Climate Solutions Now Act of 2022 requires 60 percent emission reductions of greenhouse

¹ Klepeis et. al., 2001.

<https://chronicdata.cdc.gov/500-Cities-Places/PLACES-Census-Tract-Data-GIS-Friendly-Format-2022-/yjkw-uj5s>

<https://data.imap.maryland.gov/datasets/bbe7d09a81fc40c8a7c9f4c80155842e/explore?location=38.810467%2C-77.268400%2C8.94>

gases by 2031 relative to 2006, and carbon neutrality by 2045.² Commercial and residential buildings in Maryland accounted for 55 percent of total natural gas use in 2021. These buildings will have to implement efficiency measures and electrify heating, cooking, and other end-uses in order to meet the state's climate targets. At the same time, the 2013 Strategic Infrastructure Development and Enhancement (STRIDE) Act incentivizes significant investments by gas utilities in pipeline replacement. If approved by the Public Service Commission, ratepayers will be paying for these investments decades after 2045.

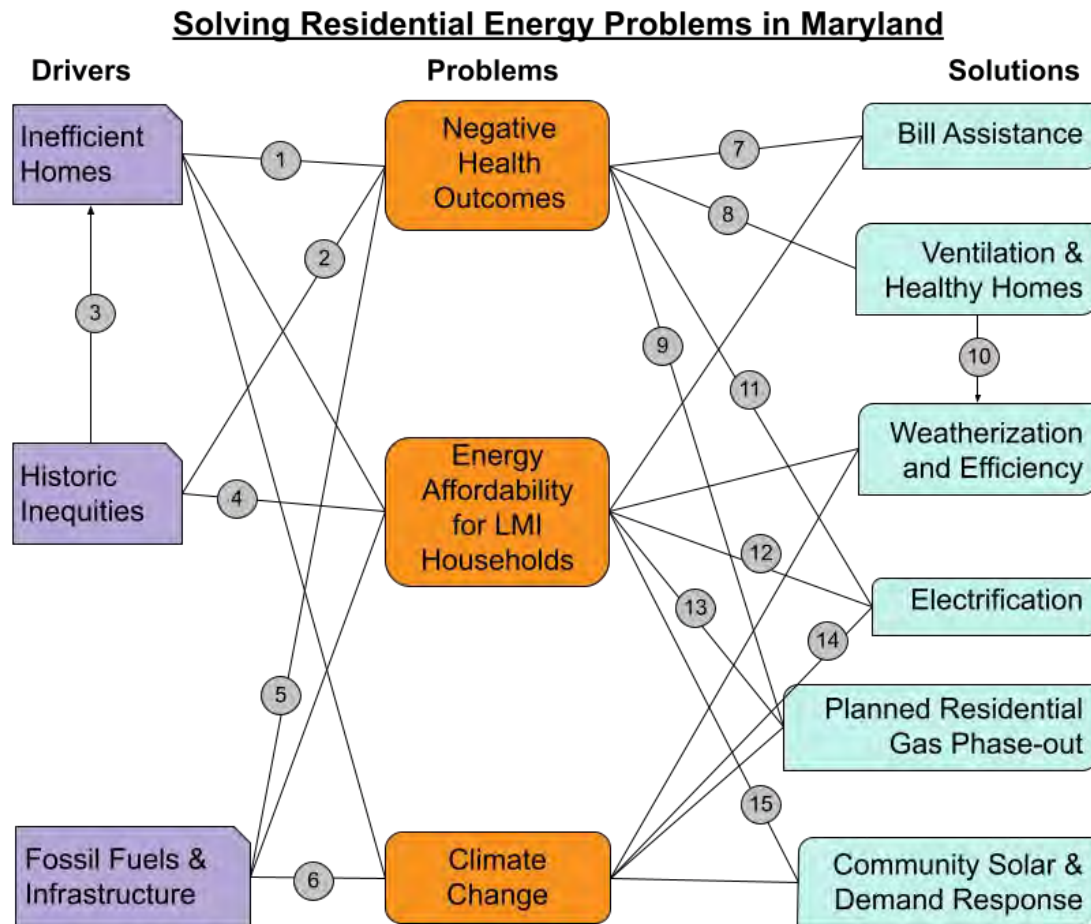
Addressing Legacy Conditions

Mitigating the affordability, public health, and climate ramifications of Maryland's residential energy system will require decarbonizing individual buildings while simultaneously addressing system-wide challenges and inequities such as historic disinvestment, incompatible energy policies, and insufficient funding and policy support for energy-burdened households. Maryland's climate strategy must address these legacy conditions to ensure that public health and energy affordability goals are also achieved.

Figure ES-4 identifies three of the core problems of Maryland's current residential energy system—affordability, public health, and climate change—alongside primary drivers and proposed policy solutions.

² Maryland General Assembly, Climate Solutions Now Act of 2022, Senate Bill 528, Effective Date June 1, 2022, at <https://mgaleg.maryland.gov/2022RS/bills/sb/sb0528E.pdf>

Figure ES-4: Core problems facing Maryland’s residential energy system, historic drivers of these problems, and potential policy solutions outlined in this report.



- 1) Inefficient homes can contribute to poor indoor environmental conditions
- 2) Inequities drive disproportionate adverse health outcomes
- 3) Homes for LMI households are less efficient on average
- 4) Disadvantaged households lack ability to improve homes and reduce energy bills
- 5) Indoor air pollution & gas transmission safety issues
- 6) CO₂ & methane emissions contribute to climate change
- 7) Reduced energy poverty helps households pay for other essentials
- 8) Reduced exposure to indoor air pollutants, allergens, and mold
- 9) Reduced exposure to gas transmission leaks
- 10) Home improvements often needed before weatherization
- 11) Electric appliances do not emit air pollutants associated with combustion
- 12) Total energy bills for efficient electric homes are typically the lowest in Maryland
- 13) Households remaining on gas lines will face higher future bills to maintain infrastructure
- 14) Efficient fully electric homes are responsible for fewer greenhouse gases
- 15) Prioritized solar and demand response for LMI households can reduce energy bills

Existing Housing Stock and Fuel Infrastructure

While low incomes are the primary driver of high energy cost burdens, as shown in **Figure ES-2**, a variety of key factors related to building stock and housing arrangements are also associated with energy unaffordability:

- **Fuel type:** Households using costly fuel oil and propane for heating, which is more common in rural areas such as the Eastern Shore, tend to have higher energy cost burdens than those heating with gas or electricity.
- **Renter status:** Low- and moderate-income households are more likely to be renters, particularly in urban areas, including Baltimore. Renters are more likely to face barriers to efficiency upgrades and other clean energy measures because these decisions are often made by landlords, while the benefits accrue to tenants, leading to a split incentive problem.
- **Home quality:** Low- and moderate-income households tend to live in homes that are less efficient per square foot, and more likely to have problems such as mold, lead, and leaky roofs. These problems must be remediated before such households can be weatherized or measures such as rooftop solar can be adopted; but resources for these upgrades are limited.
- **Demographics:** Energy costs tend to be disproportionately higher for communities of color, even when controlling for household income.^{3,4,5} Systemic and structural inequities have contributed to this disparity between racial and ethnic groups, from federal government-sponsored segregation in housing, to redlining (e.g., refusing to insure mortgages in and around Black neighborhoods).⁶ Because of such systemic exclusions, Black, Indigenous, and People of Color (BIPOC) communities also tend to live in less efficient and less healthy homes, and may experience higher costs when investing in energy efficiency upgrades.^{7,8,9}

³ Kontokosta, C., V. Reina, and B. Bonczak. (2019). "Energy Cost Burdens for Low-Income and Minority Households." *Journal of the American Planning Association* 86 (1): 89–105. doi.org/10.1080/01944363.2019.1647446

⁴ Lyubich, E. (2020). "The Race Gap in Residential Energy Expenditures". *Energy Institute at HAAS*. WP-306

⁵ Krieger, E., Lukanov, B. et al. (2020). Equity-Focused Climate Strategies for New Mexico: Socioeconomic and Environmental Health Dimensions of Decarbonization. *Physicians, Scientists and Engineers for Healthy Energy (PSE)*.
<https://www.psehealthyenergy.org/our-work/programs/clean-energy/western-states-deep-decarbonization/new-mexico/>

⁶ Gross, T. (2017, May 3). A 'Forgotten History' Of How The U.S. Government Segregated America.
<https://www.npr.org/2017/05/03/526655831/a-forgotten-history-of-how-the-u-s-government-segregated-america>

⁷ J. Lewis, D. Hernandez, and A. Geronimus. (2019). "Energy Efficiency as Energy Justice: Addressing Racial Inequalities through Investments in People and Places." *Energy Efficiency*, 13, 419–32. doi.org/10.1007/s12053-019-09820-z.

⁸ Reames, T. G. (2016). Targeting Energy Justice: Exploring Spatial, Racial/Ethnic and Socioeconomic Disparities in Urban Residential Heating Energy Efficiency. *Energy Policy*, 97, 549–558.

⁹ Reames, T. G., Reiner, M. A., & Stacey, M. B. (2018). An Incandescent Truth: Disparities in Energy-Efficient Lighting Availability and Prices in an Urban U.S. County. *Applied Energy*, 218, 95–103.

Competing Policies and Rate Structures

Certain Maryland energy policies—notably, retail choice and STRIDE—increase energy cost burdens for low-income households; the latter is poised to further exacerbate these burdens in the coming decades.

- **Retail choice:** Third-party suppliers of electricity and natural gas frequently charge rates that are higher than regulated utility “Standard Offer Service.” For low- and moderate-income households participating in retail choice, the excess cost in 2021 for electricity was at least \$30 million; for natural gas, the excess cost was about \$7 million. In all, the two add about 10 percent to the affordability gap. Due to successful advocacy efforts, a prohibition on supply at rates above Standard Offer Service to bill payment assistance recipients will be implemented in 2023. This will eliminate the excess cost for them; however, since most eligible households do not get assistance, most of the excess cost will remain until the prohibition is extended to all eligible households, whether they get assistance or not.
- **STRIDE:** Maryland’s 2013 STRIDE law—enacted to authorize and create a funding mechanism for billions of dollars in natural gas pipeline replacements—allows continued investments in existing natural gas infrastructure without a formal rate case being conducted first, with all capital costs and return on investments to be recovered from ratepayers over the next 70 years or so. This law assumes the continued use of gas pipelines. At least for residential buildings, the subject of this report, this is in contradiction with the 2022 Climate Solutions Now Act, which requires net-zero greenhouse gas emissions by 2045 and implies near-total phase out of natural gas use in residential buildings by that date. In spite of its safety ambitions, serious accident frequency data do not indicate that the 2013 STRIDE law has had an impact on reducing pipeline accidents.

If STRIDE-related investments continue to be approved and building electrification continues, consumer natural gas rates will increase significantly, likely accelerating the migration from gas to cheaper electric space and water heating options by those who can afford it. This is likely to create spiraling rate increases for households left on the natural gas system equaling roughly \$40 per million British Thermal Unit (MMBTU¹⁰) by 2040 and roughly \$100 per MMBTU by 2045, even if commodity natural gas rates do not rise. If natural gas is replaced by synthetic gas and green hydrogen, with most heating being done electrically, gas rates could increase even more, to about \$140 per MMBTU. In other words, gas prices would rise by more than

¹⁰ A thermal unit of measurement for natural gas.

three times from about \$12 per MMBTU in 2021 by 2040 and could increase by more than ten times by 2045. Low- and moderate-income households that cannot electrify completely (for instance, because they are renters) will face steeply rising energy cost burdens, putting upward pressure on the amounts needed for bill assistance.

Inadequate Bill Assistance and Support for Weatherization

Energy bill assistance can play a critical role in reducing energy cost burdens immediately, but only 26 percent of eligible households in Maryland actually received such assistance in 2021. Many of the households who receive assistance still have energy cost burdens over six percent; the vast majority of eligible households who do not get assistance are also left with unaffordable burdens.

Numerous factors may contribute to low enrollment, but most notable are the onerous application process for assistance and burdensome documentation requirements. These include proof of up to 27 data points on sources of income, social security numbers, as well as name, citizenship status, and birthdate of each member of the household; in case someone has no income, an additional declaration is required for that. The application is explicitly punitive in its tone. Moreover, there are insufficient funds to provide bill assistance to all those who need it: we estimate that current energy bill assistance needs are in the range of \$350 million to \$450 million per year. We have used \$400 million as the affordability gap in this report; about \$40 million (or more) of this gap is due to the higher rates that low- and moderate-income households pay to third party suppliers compared to Standard Offer Service rates. Once this problem is fixed (as it has been for assistance recipients) the true gap, based on regulated utility rates, is still about \$360 million. About \$120 million per year is available from current sources for bill payment and arrearage clearance assistance; this leaves a gap of \$240 million to fully fund a bill assistance program that guarantees affordable energy bills across the state, such as a Percentage of Income Payment Plan (PIPP).

Policy Solutions

We propose a mix of policy solutions to reduce energy cost burdens while achieving climate and public health goals across Maryland's residential sector. In the near term, removing barriers to enrollment in bill assistance—and adequately funding assistance programs—can help improve energy affordability for low- and moderate-income households. In the long term, this bill assistance can be reduced or even phased out for most eligible households as investments in weatherization (inclusive of public health measures such as a secure building envelope and proper ventilation), electrification of appliances, provision of discounted

community solar, residential demand response, and ultimately the retirement of the gas distribution infrastructure for buildings can help achieve climate goals while systematically reducing energy cost burdens.

Fully Funded Bill Assistance Programs with Low Barriers to Participation

Energy bill assistance can be provided in numerous forms, such as grants to reduce bills, discounted rates, or a PIPP. The latter is the most direct method for ensuring that a household's energy bills are capped at an affordable threshold. For PIPP and any other assistance measures to be effective, enrollment barriers must be removed. Applications should be simplified greatly, with upfront documentation requirements eliminated for state and ratepayer funded programs, and restructured to enable mixed immigration status households to apply without fear. Income and other facts in the application should be by self-attestation, which can be verified later with random audits.

To ensure affordability for all Maryland households, the amount of funding for assistance programs would have to be increased by about \$280 million per year under current circumstances. The amount would be reduced to about \$240 million if the ban on third party supply at rates above utility "Standard Offer Service" is extended to all households eligible for assistance. Full integration of affordability into the energy transition would require substantial additional funds; however, the vast majority of these could come from the Inflation Reduction Act until 2032.

Over time, the total amounts needed for assistance would decline to well below \$120 million, the level of currently available funds, as bills are lowered through weatherization, electrification, and discounted community solar measures. Progressive funding sources, such as a wealth tax, would limit cost shift impacts to the vast majority of non-low-income households. After full integration of all eligible households into the energy transition, the majority of them would no longer require assistance because their bills would be lowered sufficiently to be affordable. Bill payment assistance totalling about \$40 million less the amount available today for assistance would still be needed for about 60 percent of the households with income less than the federal poverty level depending on their type of home.

Weatherization, Ventilation, and Electrification

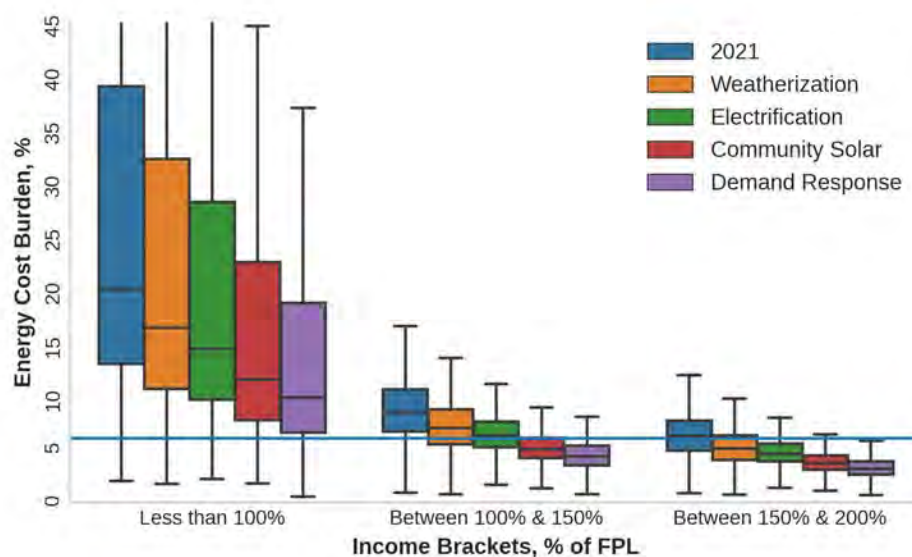
The greatest energy affordability, energy efficiency, and public health benefits will be derived when targeted weatherization, ventilation, and electrification retrofit programs are implemented carefully with a focus on low-and moderate-income households and populations most vulnerable to poor indoor air quality (e.g., children, older adults, people of

color, those with preexisting respiratory and cardiovascular conditions). Retrofit measures and benefits include:

- **Weatherization:** The current rate of weatherization of low- and moderate-income homes will need to be accelerated by five to ten times and combined with electrification in order to meet state climate targets. Accelerating low-income weatherization programs will allow the state to take full advantage of funds available under the federal Inflation Reduction Act.
- **Electrification:** Electrification of household appliances, particularly those located within the living space, e.g., stoves, ovens, space heaters, can eliminate combustion-related emissions that contribute to poor indoor air quality and increased health risks. Moreover, homes that are fully electrified using efficient technologies generally have lower bills than equivalent fossil fuel users. Policies and programs will be needed to support electrification for households that cannot afford the up-front costs, ideally replacing all fossil fuel use in a single retrofit. Priority should be given to low- and moderate income households, including renters, because (i) they are most at risk of being stranded on the gas system and facing its rising costs and (ii) the Inflation Reduction Act provides major incentives and rebates for electrification which would make it even more economical to electrify these households.
- **Solar Energy:** Virtual net metering is a valuable strategy for providing discounted electricity to low- and moderate-income households. Virtually net-metered discounted community solar electricity can play a key role in reducing energy assistance requirements. We estimate that providing discounted community solar (at 20 percent discount) can reduce energy cost burdens significantly, the more so as homes are electrified. Enabling low- and moderate-income households to participate in demand response can help bring costs down even further.
- **Ventilation:** Access to and utilization of mechanical ventilation (e.g., range hoods, HVAC systems) can aid indoor air quality by reducing indoor air pollutant concentrations attributable to combustion-based appliances. Ventilation can also provide indoor air quality benefits when electric stoves and ovens or induction ranges are used by reducing indoor air pollutant emissions related to types of foods being cooked. Educational campaigns should promote activities that increase ventilation during cooking (e.g., using range hood, opening windows) as a precaution whenever cooking occurs. High-quality ventilation systems should be prioritized when conducting energy retrofits or upgrades to ensure that household ventilation is maintained or improved when energy retrofits are implemented.

- Coupled interventions with cross-cutting benefits:** Energy cost burdens would be greatly reduced by a combination of weatherization, efficient electrification, and discounted community solar electricity supply. As a result of these investments and interventions, the funds needed for energy assistance for universal affordability will gradually decline over time. Additionally, coupled air sealing, mechanical ventilation and filtration, electrification, and educational efforts can improve both energy efficiency and indoor air quality, resulting in simultaneous benefits for climate and public health. A holistic, green and healthy homes approach should be adopted while retrofitting existing homes; grants for that purpose should be made available to owner-occupied households with incomes at or below the federal poverty level. While it is difficult to quantify the benefits of added housing security and improved health, the available evidence indicates that the non-energy benefits of making bills affordable, increased housing security, and improved air quality may well be of the same order of magnitude as the costs of added assistance and full integration into the energy transition of low- and moderate-income households.¹¹ **Figure ES-5** demonstrates how a combination of weatherization, electrification, community solar, and demand response alongside proposed financing strategies can lower energy cost burdens for each income bracket.

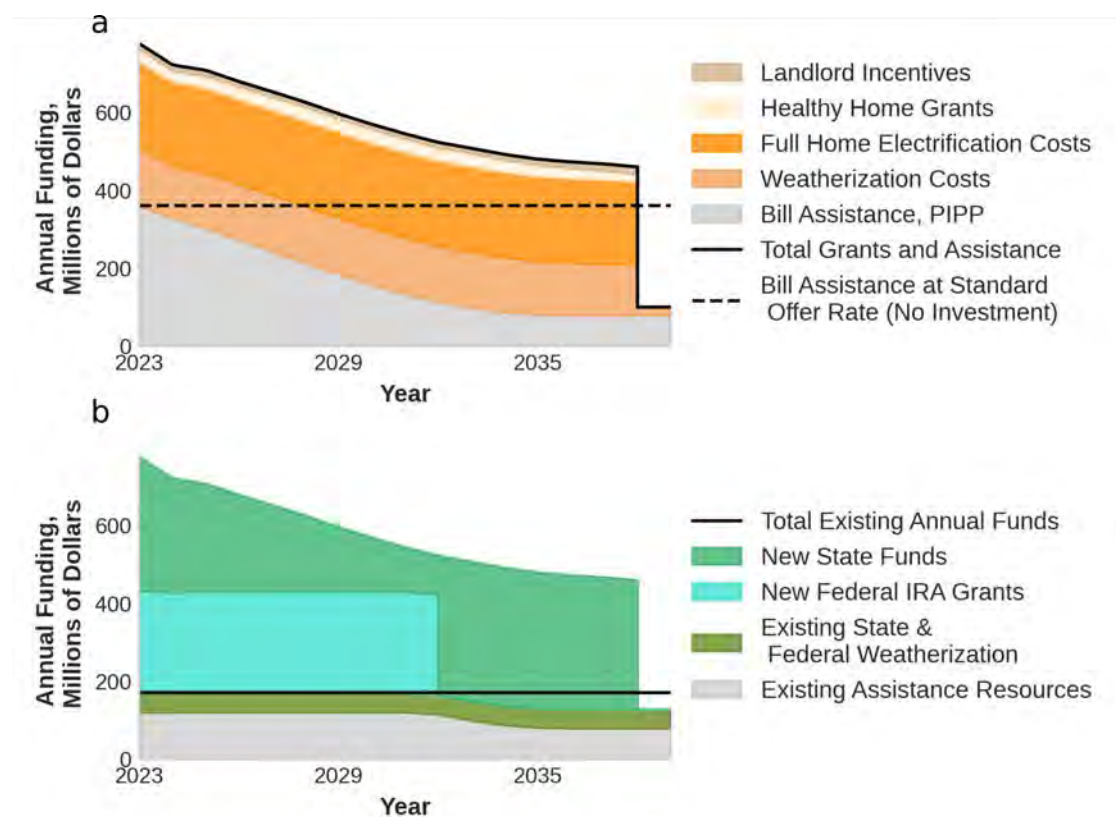
Figure ES-5: The sequential affordability benefits of weatherization, electrification, community solar, and demand response by income group.



¹¹ See **Section 5.3** for references and discussion.

Figure ES-6(a) shows the funds needed for each element of to achieve affordability for all over time; note that the need for assistance falls steadily as low-income households are fully integrated into the energy transition—with the steps shown in **Figure ES-5** above to be completed in 15 years in these calculations. **Figure ES-6(b)** shows the sources of funds, including new state funds and new federal funds available, mainly from the Inflation Reduction Act. About \$4 billion dollars in new funds would be needed (present value, three percent discount rate). About \$1 billion (2023 present value) of this cost would be offset by savings after that would continue after that at the same rate. Full integration of low- and moderate-income households into the energy transition would, over the rest of the century (the usual time for climate calculations), save a net of \$8 billion (2023 present value) relative to sustaining affordability with assistance alone.

Figure ES-6(a): Uses of funds for universal affordability and energy transition integration;
Figure ES-6(b): potential sources of funds for achieving that goal.



Gas System Planning and Retirement

As more customers electrify, costs of the gas system will be distributed among fewer households, increasing costs for the remaining customers. One solution to mitigate rising costs is to prune—that is, retire—entire sections of the gas distribution system at a time to reduce fixed costs, and electrify all affected households. Maryland should discontinue its current program of natural gas pipeline replacement under the 2013 STRIDE law and phase out the natural gas infrastructure supplying buildings, especially in the residential sector, in consonance with the Climate Solutions Now Act. Any investments needed to ensure the safety of the natural gas distribution system should be done via formal rate cases, where consideration can be given to retiring the pipelines in question and electrifying those neighborhoods. Only investments strictly needed for safety should be allowed until electrification can be carried out so that entire sections of the natural gas infrastructure can be shut down in an orderly way. Networked geothermal wells with heat pumps are emerging as an alternative to natural gas investments in areas with sufficient load density.

The vast majority of serious injuries and fatalities from natural gas explosions in recent years have occurred in apartment buildings. This needs to be investigated, including whether there have been disproportionate impacts on BIPOC and immigrant communities.

Enabling Considerations

Certain enabling considerations are critical components to ensure that energy transition programs and policies are effective and equitable. These include:

- **Holistic approach:** Energy affordability, climate change, and public health have historically been addressed in siloes, but greater benefits may be achieved by working collaboratively across agencies, programs, and sectors to identify multi-benefit strategies to decarbonize residential buildings.
- **Prioritization:** Geographically concentrated areas where the highest cost burdens and/or public health burdens are concentrated, as well as those most at risk for escalating costs during a transition, should be prioritized for interventions.
- **Community engagement:** Affected communities should be engaged up front and throughout the design, implementation, and evaluation of programs, including considerations of compensation for time to support participation.
- **Broadband:** Participation in demand response, the ability to respond to time-of-use-rates, and adoption of other distributed resources require access to

broadband and smart appliances. Ensuring universal broadband access is an important complement to an equitable energy policy.

- **Financing and grants:** Low-interest financing and grants can enable low-income households to adopt clean energy technologies with high upfront costs. Existing weatherization grant programs are funded to the tune of about \$50 million per year. The Inflation Reduction Act provides some funds for weatherization grants, incentives to landlords, and far more for heat pump electrification of space heating. Additional state-level funds, however, may be needed, such as those provided through a green bank.
- **Contract backstops and other incentives for community solar:** Low- and moderate income households are not benefiting from Maryland's community solar program to the extent they could with proper incentives for solar developers and investors. The risk profile of low- to moderate- income households with varying credit histories, combined with higher marketing and customer management costs, means that it is currently more expensive for community solar developers to serve low- and moderate-income households than non-low- and moderate-income households. Contract default backstops, provided by green banks or non-government organizations are one way to address this issue. Grants, added tax incentives and/or low-cost financing for projects serving low-income subscribers, such as those currently provided in small numbers by the Maryland Energy Administration and included in the Inflation Reduction Act, would also provide solar developers with the financial assurance needed to elect to sell to low- and moderate income subscribers.
- **Utility Consolidated Billing with Purchase of Receivables for community solar:** Even though available to all other third-party electricity suppliers, current regulations do not offer community solar developers and subscribers the benefit of Utility Consolidated Billing with Purchase of Receivables, by which the utility sends a single consolidated bill to the subscriber and purchases any debt owed by the solar subscriber to the developer. Without Utility Consolidated Billing many low-income community solar subscribers risk the loss of electricity bill payment assistance if subscribed to community solar power because bill payment assistance is currently only provided through the utility, not through the community solar provider. Utility Consolidated Billing would also allow community solar customers to pay their bills in cash or by check as part of their utility bills; low-income customers without credit or debit cards cannot currently participate in community solar.
- **Data collection and sharing:** Regular collection and transparent sharing of data regarding participation in weatherization, electrification, and bill assistance programs, and the concomitant energy and cost savings, will enable the ongoing modification of

these programs to improve effectiveness. It would also be valuable to measure indoor air pollution for a subset of households to better determine the public health benefits of selected interventions.

- **Workforce:** Over a million homes will need to be converted from fossil fuel heating technologies to highly efficient air-to-air and geothermal heat pumps. A variety of workforce development programs are needed. In addition to in-person training and apprenticeships, examples from other states include on-demand video training materials (Vermont), directories of training materials (New York) and intensive training webinars (California).¹²
- **Pilot programs:** Maryland should implement several pilot programs similar to other states to test the feasibility and economics of new technologies and programs. These include, for example, an exploration of the networked geothermal well approach for simultaneously reducing stranded costs, promoting full electrification of space heating, and reducing CO₂ emissions. New York and other states have passed laws promoting geothermal well networks; there are also examples of pilot programs.

¹² Stephen Mushegan and Claire McKenna, “Opportunities for Job Training While Sheltering in Place,” Rocky Mountain Institute, April 29, 2020 at <https://rmi.org/building-electrification-opportunities-for-job-training-while-sheltering-in-place/>

1.0 Overview of Energy Affordability

1.1 Introduction

Energy-cost-burdened households are defined as paying six percent or more of income on energy bills—a threshold met by roughly 18 percent of all Maryland households. We estimate that the total number of households with energy cost burdens more than six percent is close to 400,000. Low-income households often pay significantly more. We estimate that in 2021, about 440,000 Maryland households earned below 200 percent of the federal poverty level¹³ and around 80 percent of these households were energy cost-burdened.¹⁴ In addition there are some households with income above 200 percent of the federal poverty levels who are energy cost-burdened.

These high energy cost burdens often force households to make wrenching financial choices about paying for necessities, such as rent, medicine, and the fuel needed to heat homes. When electric bills go unpaid, utility companies may cut off electricity or natural gas and families may face eviction. These events have ripple effects throughout the economy. A 2015 analysis of energy affordability in Maryland estimated that each incidence of homelessness lasted seven months on average and cost an added \$28,000 per displaced family, in addition to the losses and distress suffered by the family.¹⁵

¹³ APPRISE. *2018 National Energy Assistance Survey: Final Report*. Prepared for National Energy Assistance Directors' Association. Washington, DC: NEADA, December 2018.

<http://www.appriseinc.org/wp-content/uploads/2019/02/NEADA-2018-LIHEAP-Survey.pdf> p. ii

¹⁴ The energy affordability threshold is derived first of all from the U.S. Department of Housing and Urban Development definition of affordable housing costs as being 30 percent of income, including utility bills. Legal Guide to Affordable Housing Development (2nd ed.). *American Bar Association*. Twenty percent of the housing cost — that is, six percent of overall income — is considered an affordable energy cost burden, according to Fisher, Sheehan and Colton, with a sublimit of two percent for heating and cooling costs alone: Fisher, Sheehan, and Colton. (2021). Home Energy Affordability Gap. *Public Finance & General Economics*. http://www.homeenergyaffordabilitygap.com/03a_affordabilityData.html The six percent threshold is also defined as the affordability limit by the American Council for an Energy Efficient Economy: see Dreihobl, A. and Ross, L. (2016). Lifting the High Energy Burden in America's Largest Cities: How Energy Efficiency Can Improve Low-income and Underserved Communities. *American Council for an Energy-Efficient Economy (ACEEE)*. <https://aceee.org/research-report/u1602>; and Dreihobl, A., Ross, L., and Ayala, R. (2020). How High are Household Energy Burdens? *American Council for an Energy-Efficient Economy (ACEEE)*.

¹⁵ Arjun Makhijani, Christina Mills, and Annie Makhijani, *Energy Justice in Maryland's Residential and Renewable Energy Sectors*. Takoma Park Maryland: Institute for Energy and Environmental Research. (2015). <https://ieer.org/wp/wp-content/uploads/2015/10/RenMD-EnergyJustice-Report-Oct2015.pdf> pp. 89-91.

The decarbonization of Maryland’s energy system under the Climate Solutions Now Act¹⁶ creates the potential to alleviate energy cost burdens, or to exacerbate them. Likewise, there is an opportunity to simultaneously improve public health by phasing out the use of fossil fuels in homes—thereby eliminating associated emissions of health-damaging air pollutants—and adopting a holistic approach to retrofits that support the addition of proper envelope sealing and ventilation to achieve these health goals, particularly for low-income households. In this chapter, we examine Maryland’s past efforts to reduce energy cost burdens and provide a summary of existing programs, funding levels, and effectiveness to provide a comprehensive view of obstacles and opportunities to achieving universal energy affordability. In **Chapter 2**, we analyze energy cost burdens statewide and examine the gap between existing energy costs and affordable costs. **Chapter 3** addresses the indoor air quality and public health implications of residential energy use. **Chapter 4** explores the contradictions between existing policies that allow continued investments in natural gas infrastructure under a 2013 law and the 2022 Climate Solutions Now Act. In the final **Chapter 5**, we analyze the policy changes that will be needed to make the energy transition an instrument of equity, health, and affordability.

1.2 Maryland’s Energy Affordability Landscape

Maryland had a population in 2021 of about 6.1 million people, of whom nine percent lived below the federal poverty level; there were about 2.3 million households in 2021. Maryland’s median household income was about \$91,000¹⁷ the highest in the United States. Yet, about 400,000 households were energy cost-burdened; we estimate that the total gap between the actual energy cost burden for all these households and six percent of income was approximately \$400 million.¹⁸ At the lowest income level, less than 50 percent of the federal poverty level, energy cost burdens in Maryland approach and sometimes exceed 40 percent of income. When income is in the range of 50 to 99 percent of the federal poverty level, energy cost burdens are typically 15 to 20 percent of income. Without explicit policies and actions to alleviate them, high energy cost burdens are likely to be exacerbated by the transition to a decarbonized energy system.

High energy cost burdens are part of the mix of severe financial stresses that result in people not buying enough medicine to take as prescribed or postponing payment of utility bills. Cascading problems can follow. For instance, utility shut-offs can aggravate health problems

¹⁶ Maryland General Assembly, Climate Solutions Now Act of 2022, Senate Bill 528, Effective Date June 1, 2022, at <https://mgaleg.maryland.gov/2022RS/bills/sb/sb0528E.pdf>

¹⁷ Maryland Quick Census Facts 2017-2021; at <https://www.census.gov/quickfacts/fact/table/MD/PST045221>

¹⁸ **Chapter 2**

or result in eviction. The National Energy Assistance Directors' Association periodically surveys families who have received federal assistance (via the states) to help pay their heating bills. The findings of a recent survey (2018)¹⁹ were stark:

- More than one out of seven households surveyed had had their electricity or natural gas supply cut off because of their inability to pay their utility bills—and nearly half of these households resorted to using candles or lanterns for lighting;
- Nearly one in three families were using the stove or oven for heating—a problem known to exacerbate indoor air pollution;
- Over one in three households went without food for at least a day and nearly a third of the families were unable to afford medicine at all or unable to purchase the full doses of medicines they needed at least once in the past five years.

Loss of homes due to conflicts between paying utility bills or paying the rent or mortgage is among the most devastating outcomes. The survey found that 23 percent—nearly one in four—of the households who received assistance at least once in the past five years had lost their homes within that time due to a variety of financial stresses, including utility bills and rent/mortgage payment conflicts. This is an average of nearly five percent every year. About three-fourths of affected households found shelter with friends and family; one-fourth became homeless.²⁰

1.1.1 Existing State and Federal Policies

In Maryland, like other states, the serious impacts of high energy cost burdens have led to a variety of policies and approaches to reduce them. Several streams of funding provide assistance to low-income households:

1. **Low-Income Home Energy Assistance Program (LIHEAP):** Funded by the federal government, this program goes by the name Maryland Energy Assistance Program (MEAP).²¹ These funds are also used to assist households who use non-regulated fuels, specifically fuel oil and propane.

¹⁹ APPRISE. *2018 National Energy Assistance Survey: Final Report*. Prepared for National Energy Assistance Directors' Association. Washington, DC: NEADA, December 2018.

<http://www.appriseinc.org/wp-content/uploads/2019/02/NEADA-2018-LIHEAP-Survey.pdf> p. ii.

²⁰ *ibid.*

²¹ Office of Home Energy Programs. *Electric Universal Service Program Annual Report to the Maryland Public Service Commission: Fiscal Year 2021*. Baltimore, Maryland: Maryland Department of Human Services, December 2021, at

https://webapp.psc.state.md.us/newIntranet/Casenum/NewIndex3_VOpenFile.cfm?FilePath=//Coldfusion/Case num/8900-8999/8903/579.pdf; hereafter OHEP 2021.

2. **Universal Service Protection Program (USPP):** This Public Service Commission regulatory program is designed to help MEAP participants avert utility shut-offs. USPP requires participation in a budget billing program, which evens out monthly utility bill payments based on the prior year's average. Customers are kept apprised of actual usage and the amount is adjusted during the year, if needed.
3. **Electric Universal Service Program (EUSP):**²² This ratepayer- and RGGI²³-funded program is used to reduce electricity bill burdens by providing a credit on the customer's electric bill. Some of the funds are also used to help customers clear accumulated arrears and for weatherization of homes, at most once in five years. There is no specified affordability target that the program seeks to achieve.²⁴ It is provided in addition to LIHEAP assistance. Since 2016, LIHEAP requires states to report on how well they are targeting households with the highest energy cost burdens; there has been steady progress in energy cost burden reductions for the targeted group since that time. Bill assistance eligibility criteria for the EUSP program have been the same as for the state's LIHEAP program (MEAP), though they have now been expanded from the 175 percent of federal poverty level for MEAP to 200 percent in the case of families with at least one household member over 67 years old.²⁵ The Electric Universal Service Program has two sources of funds:
 - a. A charge on electricity sold, paid by ratepayers;
 - b. Half of the funds in the state's Strategic Energy Investment Fund (SEIF). Almost all of the funds for SEIF come from the sale of CO₂ allowances as part of the multi-state RGGI cap-and-trade program.²⁶
4. **Private charities:** The Fuel Fund of Maryland²⁷ and others supplement these federal and state programs. Sources of funds include utilities and charitable contributions.

²² OHEP 2021.

²³ Regional Greenhouse Gas Initiative

²⁴ The annual program report states the purpose as follows: "The Electric Universal Service Program ("EUSP"), enacted in the Electric Customer Choice Act of 1999 ("the Act"), was designed by the Maryland General Assembly to assist low income electric customers to retire utility bill arrearages, to make current bill payments, and to access home weatherization following the restructuring of Maryland's electric companies and electricity supply market." OHEP 2021, p. 1.

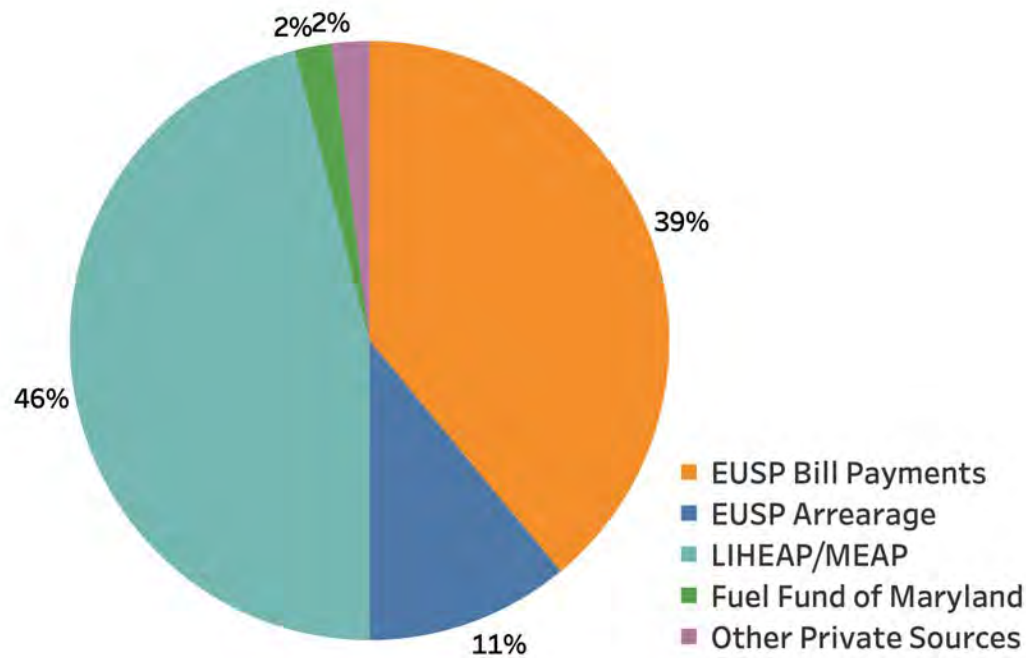
²⁵ Maryland House of Delegates, House Bill 606, 2021, at <https://legiscan.com/MD/text/HB606/2021>

²⁶ Strategic Energy Investment Fund. Activities for FY 2021, Volume 1. Baltimore, Maryland: Maryland Energy Administration, 2021, at <https://energy.maryland.gov/SiteAssets/Pages/Strategic-Energy-Investment-Fund-%28SEIF%29-/FY21%20SEIF%20Report%20Vol%201%20Final.pdf>; hereafter SEIF 2021.

²⁷ [Fuel Fund of Maryland](#) is the largest such charity. Small amounts also come from other charities. Among the private sources, only Fuel Fund resources have been included in this analysis.

Figure 1-1 shows the various sources of assistance in 2019, totalling about \$122 million.

Figure 1-1: Sources of bill payment and arrearage assistance in Maryland in 2019. The total for 2019 was \$122 million.



In-kind resources also contribute to the assistance programs. Specifically, there are a large number of volunteers who work with low-income households, the elderly, people with critical medical needs, and others who need guidance to navigate the process of applying for and receiving assistance.²⁸

In addition to direct assistance, weatherization and energy efficiency measures are used as a complement to assistance to lower energy bills and energy cost burdens. Maryland implements weatherization for low- and moderate-income households under three major programs, with total funding per year in the period 2017 to 2019 being about \$30 million, including administrative expenses:²⁹

²⁸ [The Cancer Support Foundation](#) is a leading Maryland non-profit in this arena.

²⁹ Report Greenhouse Gas Emission Reductions for CY 2019 Energy Efficiency for Affordable Housing, State of Maryland 2020, pdf. Pp. 1-2 2 and pdf p. 6, at

- The federal Weatherization Assistance Program (WAP), funded by the Department of Energy;
- The EmPOWER program, which is the state's efficiency program funded by ratepayers and regulated by the Public Service Commission. It incentivizes efficiency, including weatherization for all households—both owner-occupied and rented. The program provides cost-free weatherization and efficiency measures for low- and moderate-income households. Detached single-family as well as multi-family structures are covered.
- The MEAP emergency program, which repairs or replaces HVAC equipment in cases where equipment has failed.

The above three programs are run by the Maryland Department of Housing and Community Development (DHCD). In addition, the Maryland Energy Administration provides funding for retrofitting low- and moderate-income (LMI) households to a number of local governments and their agencies as well as to a variety of nonprofits. The budget for FY2023 is \$16.5 million.³⁰ There are also charitable efforts that fund retrofits. In total the existing funding for retrofits for LMI housing amounts to approximately \$50 million per year. Weatherization is done at no cost to income-eligible homeowners who are living in their homes. For EmPOWER programs, landlords are required to furnish 50 percent of the cost of weatherization when high cost appliances, including heat pumps and air-conditioning, are involved, either from their own funds or other resources.³¹

Federal and state programs, as well as private funders and local governments, provide funding streams for these efforts. The federal government provides funds for efficiency improvements through the WAP; there are also other sources as well, such as the state's efficiency program. The state's community solar program has a low-income component whereby the state provides subsidies to enable developers to offer deeply discounted subscriptions to low-income households. The two in combination can significantly reduce energy bills. About \$50 million a year is currently devoted to weatherization and efficiency programs, as noted above.

<https://mde.maryland.gov/programs/Air/ClimateChange/MCCC/Publications/2020%20DHCD%20Agency%20Report.pdf>

³⁰ FY23 Low to Moderate Income Energy Efficiency Grant Program, Maryland Energy Administration, viewed on December 14, 2022, at <https://energy.maryland.gov/govt/pages/cleanenergy/lmi.aspx>

³¹ Housing and Energy Programs, Energy Efficiency Program Operations Manual v.3, Department of Housing and Community Development, 2021, p. 12 and pp. 48-50, at <https://dhcd.maryland.gov/Residents/Documents/wap/EnergyEfficiencyProgramOperationsManualv.3-2021.pdf> [dhcd.maryland.gov]

Finally, state, local, and private funds are also used to facilitate access to rooftop and community solar energy.³² Maryland has a pilot program for community solar that includes incentives for participation by low- and moderate-income households. A principal aim for the pilot program is to provide renewable electricity to low- and moderate-income households at rates that are substantially lower than normal residential rates offered by utilities, enabling them to reduce their energy cost burdens. As will be discussed in **Chapter 5**, an outstanding policy issue is to ensure that the energy cost burden reductions from community solar participation are fully complementary to the state's energy assistance programs.

1.1.2 Effectiveness of Existing Policies

Both energy bill assistance and weatherization programs are assessed in this report by two principal metrics: the fraction of eligible households that participate in the program and the extent to which the programs make energy bills affordable—that is, bring them to six percent of income or lower. A related metric is whether eligibility policies include all households that have energy cost burdens of more than six percent of income. The principal state criterion to qualify for all energy bill assistance programs is household income at or below 175 percent of the federal poverty level. The number of eligible households in 2021 was about 364,000, down somewhat from its peak of about 393,000 in 2016.³³ Eligibility was expanded by a 2021 law to include households with incomes up to 200 percent of the federal poverty level if the household had someone 67 years or older.³⁴ This leaves out the thousands of households in the 175 percent to 200 percent of federal poverty level range—or higher—who do not have an older adult in the household but do have energy cost burdens of more than six percent. Were the eligibility increased to 200 percent of the federal poverty level across the board, the total number of eligible households would be about 440,000.

In 2021, there were about 364,000 Maryland households eligible for MEAP (the name for LIHEAP in Maryland) under the 175 percent criterion.³⁵ However, only about 24 percent of those received MEAP assistance. While about three-quarters of qualified Maryland households do not receive MEAP grant assistance, the state's assistance rate for heating is still higher than the majority of states (**Figure 1-2**).

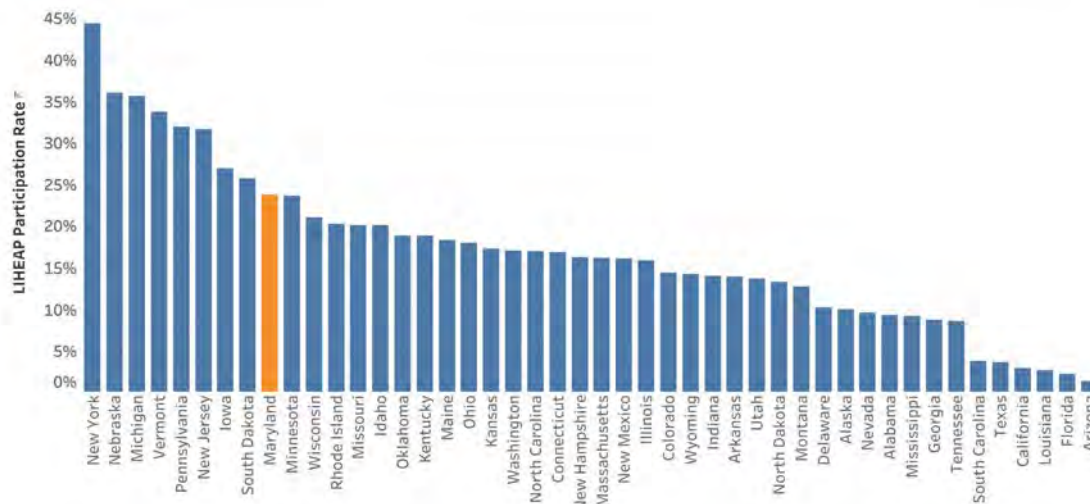
³² [Civic Works](#) is an example of a non-government organization that does weatherization and solar installations for low- and moderate-income households. Baltimore Shines is a collaboration between Civic Works and the Baltimore City government.

³³ Custom report for Maryland of eligible households in Maryland compiled from the LIHEAP Data Warehouse, at https://liheappm.acf.hhs.gov/datawarehouse/custom_reports compiled on December 3, 2022

³⁴ Office of Home Energy Programs. Electric Universal Service Program: Proposed Operations Plan for Fiscal Year 2022. Baltimore, Maryland: Maryland Department of Human Services, December 2021, at https://webapp.psc.state.md.us/newIntranet/Casenum/NewIndex3_VOpenFile.cfm?filepath=/Coldfusion/Casenum/8900-8999/8903/Item_569\EUSP_OPERATIONSPLAN_2022.pdf; hereafter OHEP 2022 Plan

³⁵ LIHEAP Data Warehouse at <https://liheappm.acf.hhs.gov/datawarehouse>

Figure 1-2: LIHEAP participation rates by state, 2021. Percentage of eligible households that received assistance from the federal LIHEAP program (administered by the states) in Fiscal Year 2021, by state according to state eligibility criteria—all types of assistance. *Source: LIHEAP data warehouse.*³⁶



The number of households receiving assistance has declined significantly in the last decade. The vast majority of those who receive MEAP heating assistance also receive electricity bill payment assistance. **Figure 1-3** shows that the number of EUSP recipients has declined sharply from a peak of above 130,000 in 2011 to about 85,000 in 2021. The chart also shows the average amount of electricity bill payment assistance per household served in current (i.e., non-inflation adjusted) dollars. The assistance per household has fluctuated a good deal; although it has risen from its 2012-2015 low, it is still well below the high of the 2007-2010 period. Energy assistance appears to have risen in the 2007-2010 period at least partly in response to the precipitous rise in electricity rates during that time; rates rose by 16 percent from 2007 to 2008 and another 8 percent in the subsequent year.³⁷

³⁶ Custom report compiled from the LIHEAP Data Warehouse at <https://liheappm.acf.hhs.gov/datawarehouse>

³⁷ Calculated from the Maryland State Electricity Profile, Energy Information Administration, Table 8. The full set of tables can be downloaded at https://www.eia.gov/electricity/state/maryland/state_tables.php

Figure 1-3: Maryland Electric Universal Service Program: Evolution of customers served and average assistance per customer per year, current dollars, not adjusted for inflation. *Source: OHEP 2021, Table 1.*

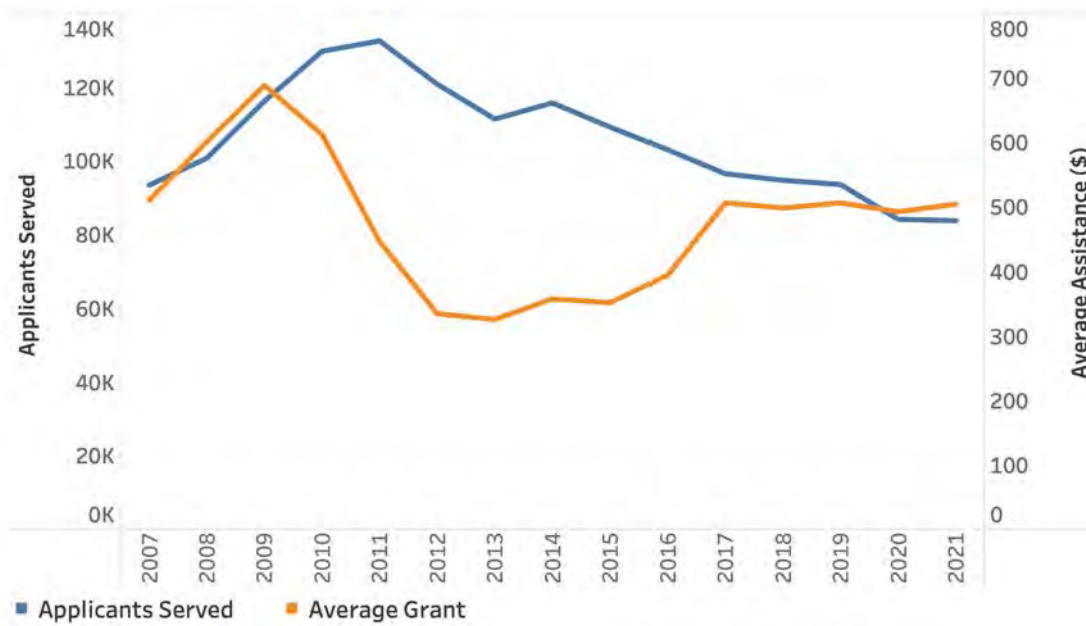


Figure 1-4 shows that the number of applicants for assistance has stayed roughly steady over the last decade; however, the rate of denials crept up in 2016 and stayed high, and then rose sharply during the COVID-19 pandemic, with about 40 percent of the applicants being denied.

Figure 1-4: Energy assistance applications, acceptances and denial rates. Source: Office of Home Energy Program Reports to the Maryland Public Service Commission, Docket No. 8903, Various Years, at: <https://webpsc.psc.state.md.us/DMS/case/8903>

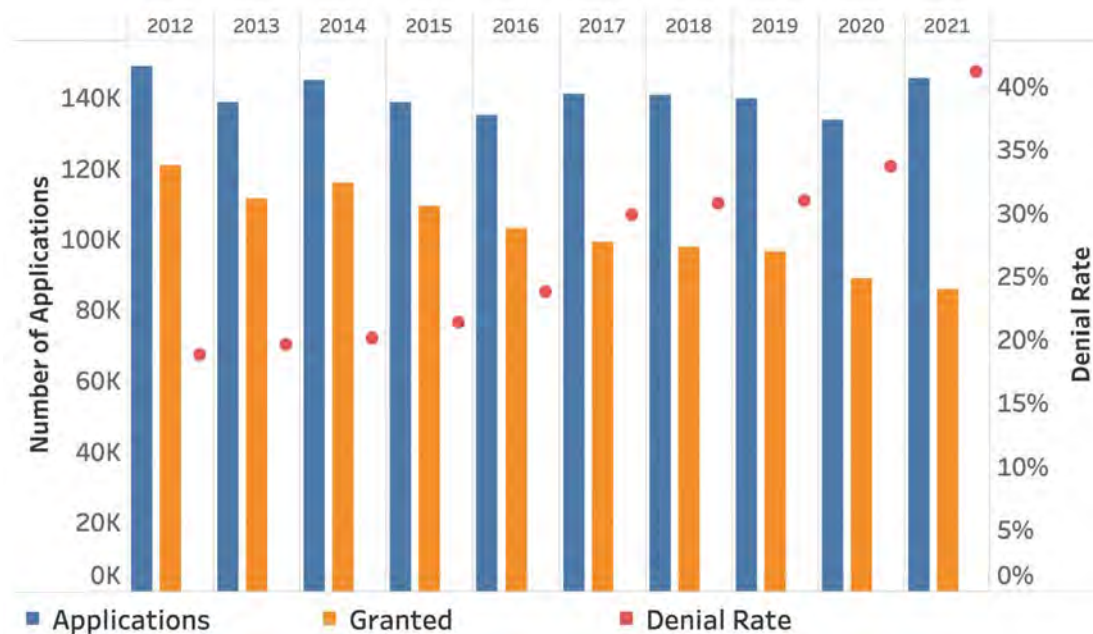
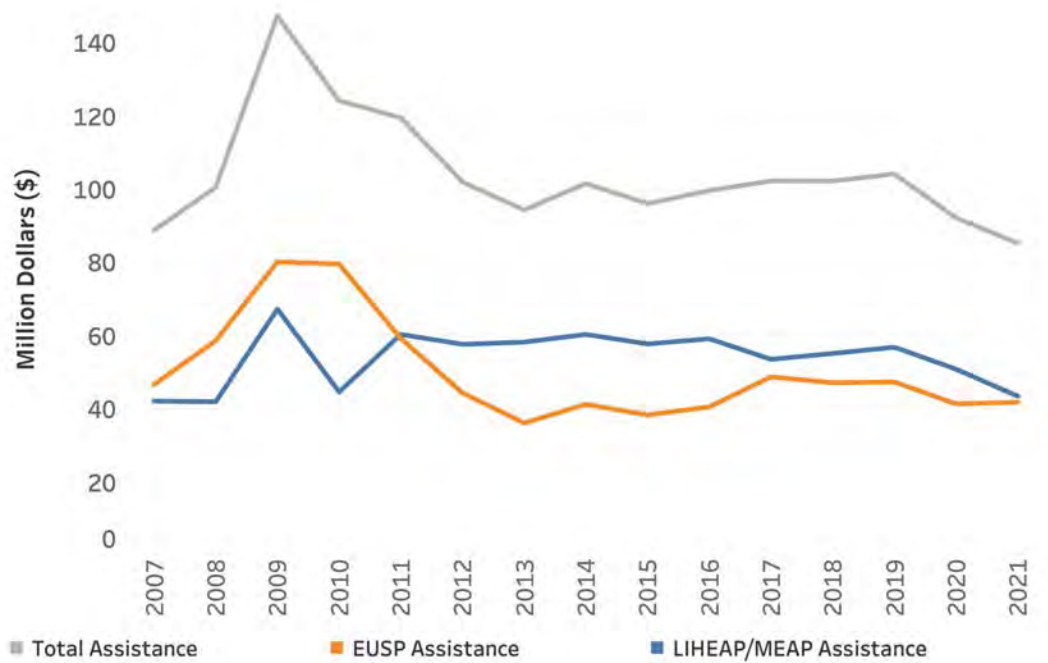


Figure 1-5 shows the combined MEAP and EUSP assistance amounts disbursed in the period since 2007. Some of the assistance is for clearing arrearages, which is included in the EUSP total. Approximately 15,000 households received assistance in 2021 to clear their electric bill arrearages so that they can start afresh. A household can receive arrearage clearance assistance at most once in five years. The totals in each category are in millions of current dollars. Total assistance has declined from the peak of 2008 when there was a severe economic recession. The dollar amounts disbursed have been approximately constant since about 2013; hence the assistance in inflation-adjusted dollars has actually declined, as was pointed out by the Office of People’s Counsel in its 2021 filing with the Public Service Commission:

The decline in BPA [Bill Payment Assistance] cannot be truly appreciated using nominal dollar amounts that do not reflect the effect of inflation....When these inflation-adjusted values are plotted...a clear decline in the purchasing power

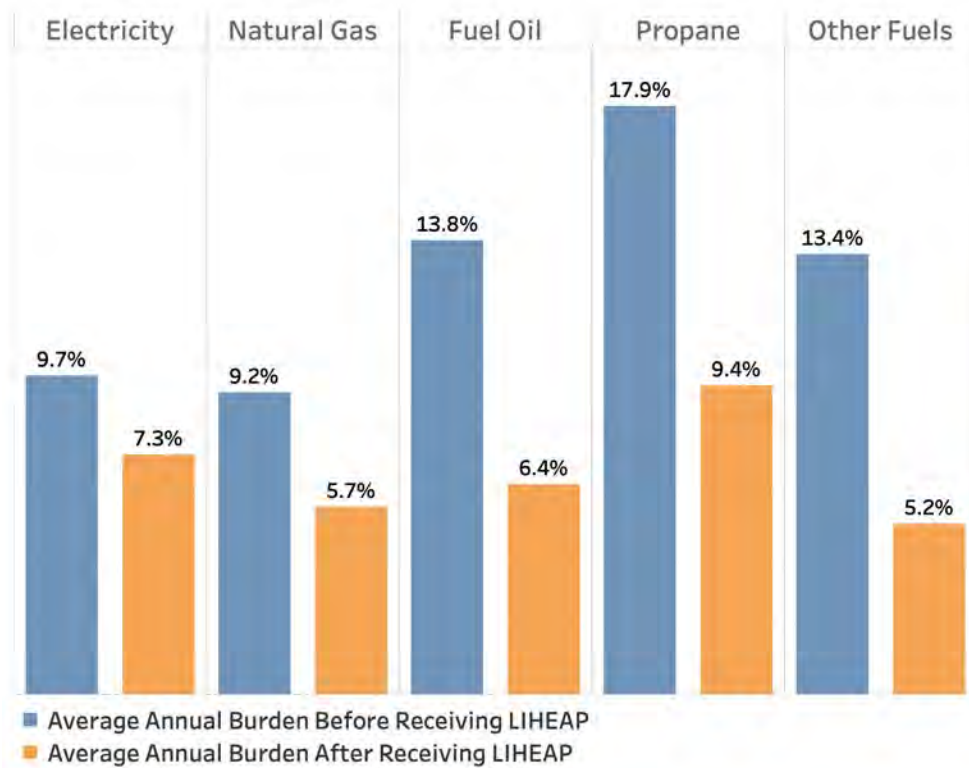
of the EUSP BPA benefit is revealed. In fact, the average BPA benefit OHEP paid to participants in FY 2021 (\$504) was over \$368 less than the inflation-adjusted value of the BPA paid to customers in FY 2009 (\$872.19).

Figure 1-5: EUSP, MEAP, and total assistance amounts to all households receiving energy bill payment assistance, including arrearages cleared. *Source: OHEP 2021, Tables 1 and 2.*



Overall, only about 26 percent of eligible households received some form of bill payment assistance in 2019, including amounts credited to utility bills and arrearage clearance. Most eligible households never apply. Those who receive assistance usually receive support through both MEAP and EUSP, lowering their energy cost burdens. In some cases, such as households using gas for heating, energy cost burdens are actually lowered, on average, to below six percent of income. However, many households despite the assistance still remain over the generally accepted affordability norm of six percent of household income, in particular those using propane, as can be seen in **Figure 1-6** below.

Figure 1-6: Pre- and post-LIHEAP energy cost burdens, by heating fuel type, 2020. *Source:* OHEP 2022 Plan, Table 9.

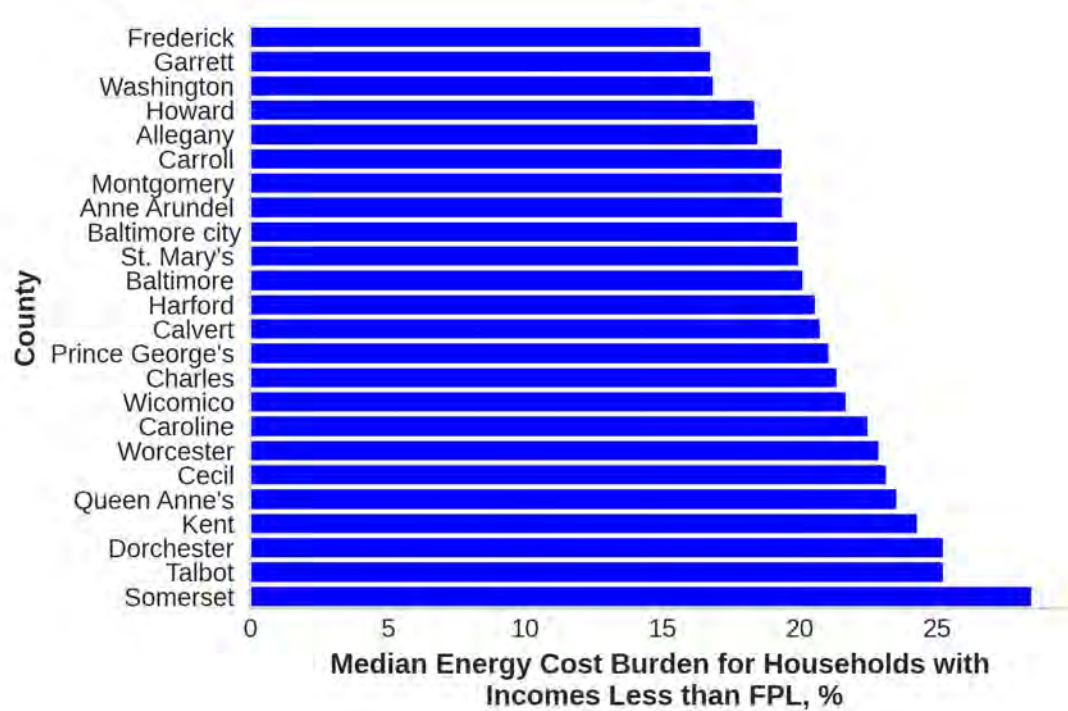


As noted, the main problem is that the vast majority of eligible households do not receive assistance for a variety of reasons. The number of households getting assistance has actually declined over time, from about 134,000 who got LIHEAP assistance in 2010 to just 88,600 households in 2020.³⁸

The severity of the energy cost burden problem for the lowest income bracket—those earning less than 50 percent of the federal poverty level—is shown, by county, in **Figure 1-7**. There were more than 75,000 Maryland households in this category in 2021.

³⁸ OHEP 2021, Table 2. A recent paper published by the Just Solutions Collective has explored the many barriers facing low-income households in applying for and getting assistance as a major reason for the generally low rate of eligible households benefiting from energy assistance programs. Zully Juarez, *Energy Burden and the Clean Energy Transition: Challenges and just solutions from energy assistance practitioners and advocates from around the country*, Just Solutions Collective, 2022, at https://assets-global.website-files.com/5fd7d64c5a8c62dc083d7a25/6246ab05aca2107884fb1632_Energy%20Burden%20and%20the%20Clean%20Transition%20-r4.pdf

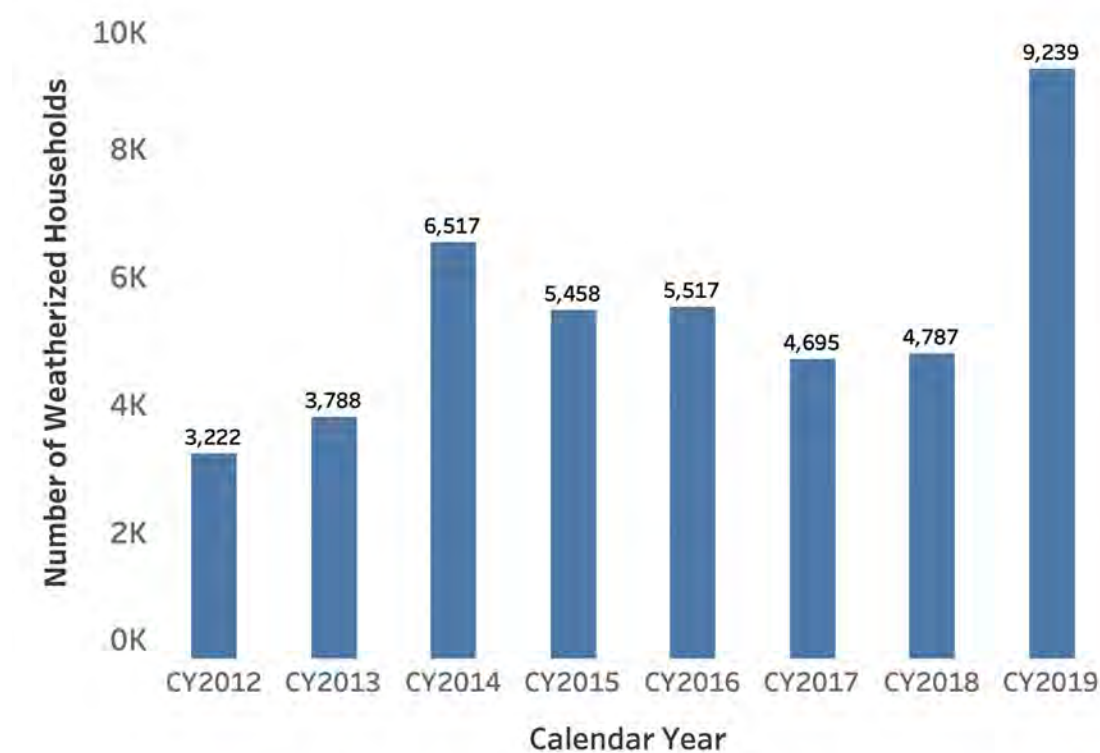
Figure 1-7: Estimated median energy cost burdens for Maryland households with incomes less than the federal poverty level, 2021.



Beyond programs for bill payment and arrearage assistance, Maryland's weatherization program is a principal strategy designed to reduce energy bills for low-income households.

Figure 1-8 shows the number of weatherizations of low- and moderate-income households carried out using funds from state and federal sources.

Figure 1-8: Low- and moderate Income households receiving weatherization services in Maryland. Source: Report Greenhouse Gas Emission Reductions for CY 2019 Energy Efficiency for Affordable Housing, State of Maryland 2020, p. 2.



Since 2021, households with incomes less than 200 percent of the federal poverty level or less than 80 percent of the area median income are eligible for free weatherization through DHCD programs; thus, as of 2022, the eligibility for weatherization is more expansive than the eligibility for bill payment assistance. Almost half-a-million households are eligible for free efficiency improvements in Maryland. The application for bill payment assistance has a check-off box for customers to indicate whether they want such investments.³⁹

³⁹ Office of Home Energy Programs, State of Maryland, assistance application at https://dhs.maryland.gov/documents/DHR%20Forms/FIA%20Forms/English/OHEP/OHEP_Application_2023_EN_Fillable.pdf In the rest of this report, we use the term “weatherization” to include both improvement of building envelope performance and appliance efficiency improvements.

Historically, the actual number of weatherization participants, shown in **Figure 1-8**, has been an order of magnitude or more lower than the number of households getting bill payment assistance (**Figure 1-4** above). A 2020 report by the Department of Housing and Community Development on the weatherization program noted that the vast majority of cases where applicants for assistance indicate they want to participate in the weatherization program do not result in actual projects:

DHCD receives a large number of client referrals through OHEP's energy assistance program, Network Partners, and other referring organizations. A high percentage (80-85%) of these leads do not convert to on-site projects for various reasons—clients may become unresponsive or do not fully understand the value in energy efficiency programs, and many renters cannot gain landlord consent for participation.⁴⁰

Historically, only about one percent of eligible households have actually been able to participate in weatherization programs each year. In theory, this low rate means that it would take a century to weatherize all eligible homes; in practice it means that many or most eligible homes will never be weatherized. Recognizing this problem, the Department of Housing and Community Development has increased its target for annual weatherizations several fold for the current 2021-2023 program period.⁴¹

The Maryland Department of Housing and Community Development also finances “Net Zero or Net Zero Ready” construction for both single-family and multi-family affordable housing.⁴²

1.3 Summary

Low- and moderate-income Marylanders routinely experience high energy cost burdens with adverse impacts on health, housing stability, and family finances. State assistance programs have effectively reduced energy cost burdens below six percent of income for many households, but energy remains unaffordable for many, despite assistance. However the largest problem by far is that they only reach slightly more than a fifth of eligible households. What's more, the proportion of households receiving assistance has been declining, exposing the vast majority of energy cost-burdened households to financial hardship.

Besides ratepayers, unaffordable energy bills also create costs for taxpayers, insurance companies, and non-profit service agencies. For example, when low-income families become homeless due to financial stresses, state and local governments cover the cost of shelter.

⁴⁰ 2021-2023 EmPOWER Maryland Program: Limited Income Program, Department of Housing and Community Development, August 31, 2020, p. 12.

⁴¹ Ibid. p. 9

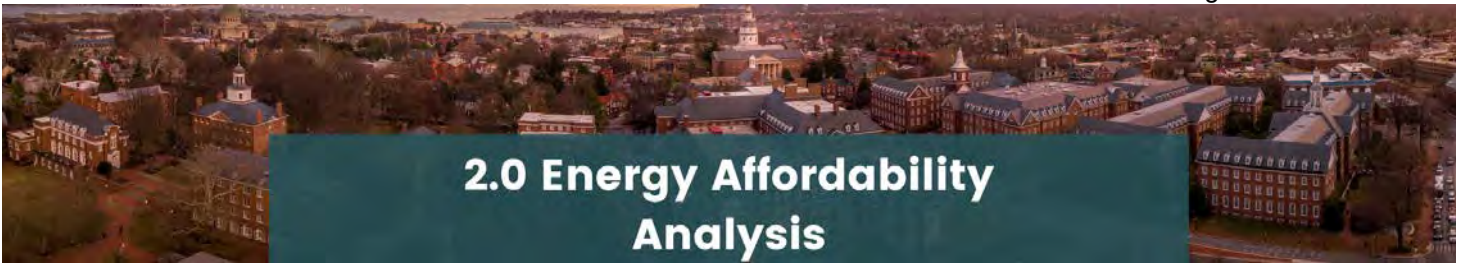
⁴² Ibid., p. 86

Homeless families tend to need more emergency room visits, the costs of which are covered by some combination of insurance companies, hospitals, and taxpayers.

The federal government provides funds for WAP; there are also other sources as well, like the state's efficiency program; these reach only about one percent of the eligible households every year. The state's community solar pilot program has a low-income component whereby the state provides subsidies to enable developers to offer deeply discounted subscriptions to low-income households. The two in combination can significantly reduce energy bills. Both are discussed in **Chapter 5** on policy.

In this report, we focus on residential buildings only since the issue of affordable energy applies to that set of structures; we note here that some of the policies and strategies in relation to climate change mitigation would also apply to commercial buildings.

In **Chapter 2** we explore the landscape of energy cost burdens and estimate the gap between present bills and affordable bills, defined as six percent of income.



2.1 Introduction

In this chapter we examine various aspects of high energy cost burdens, including their causes, in geographic, technical, and demographic detail. This analysis is essential to understand the scope of the problem and the policies and strategies that can be used to address it (**Chapter 5**). For instance, energy cost burdens for rural homeowners are often correlated with propane costs, while city dwellers are more likely to be impacted by fluctuations in the price of natural gas. A detailed analysis of Maryland's existing energy cost burdens is therefore critical to identify the characteristics of communities and populations who may struggle to pay their energy bills and the most effective strategies to alleviate these burdens. Here we analyze energy cost burdens in geographic detail and by income bracket to help determine priority areas, housing types, and income groups that most need relief. The analysis also shows where clean energy investments might result in the greatest systemic reductions in energy bills to reduce the need for bill assistance to achieve affordability.

We first estimate the distribution of existing energy cost burdens across the state of Maryland. We then analyze trends in energy affordability across the Eastern Shore, Central Maryland, and Western Maryland and identify specific demographic groups, geographic regions, and populations that struggle to pay their energy bills. The goal of this analysis is to a) provide an energy affordability baseline against which the effectiveness of future initiatives can be measured and b) provide the data needed to tailor policies and programs to at-risk demographic groups and geographic regions. We discuss policies and programs that may help alleviate these burdens in the **Policy Section (Chapter 5)**.

2.2 Measuring Affordability

By definition, variations in energy cost burdens depend on differences in energy costs and incomes. Because incomes are more variable than energy costs, they are the primary determinant of high energy cost burdens. Low-income households typically spend a larger fraction of their income on energy bills compared to other income groups, even though low-income households tend to consume less energy per household on average.⁴³ However,

⁴³ Krieger, E., Lukanov, B., Krieger E. et al. (2020). Equity-Focused Climate Strategies for Colorado: Socioeconomic and Environmental Health Dimensions of Decarbonization. *Physicians, Scientists, and Engineers for Healthy Energy*.

energy costs are still an important factor in determining energy cost burdens and vary substantially across different geographic regions,⁴⁴ climate zones, utility service areas, home types, and fuel types.

KEY FINDINGS

- Maryland has an affordability gap of \$400 million; current annual assistance funds of \$120 million only cover 30 percent.
- Higher electricity bills from third-party retail choice suppliers are responsible for roughly \$30 million of the affordability gap; another \$7 million is due to higher gas rates.
- Approximately 400,000 Maryland households are energy cost burdened—spending more than 6 percent of their income on energy.
- 90 percent of energy-cost-burdened households have incomes less than twice the Federal Poverty Level. Half of all energy-cost-burdened households are renters.
- Urban energy cost burdens are typically concentrated in certain neighborhoods, including historically red-lined areas.
- In Baltimore City, Black households spend on average 4 percent of their income on energy compared to 2.3 percent for the rest of Baltimore City’s population.
- Rural homes reliant on expensive fuels—propane and fuel oil—in areas such as the Eastern Shore are the most cost-burdened, with very high energy bills.
- Targeted interventions for low- and moderate-income households can reduce annual affordability gaps from \$400 million to \$80 million while also helping to meet carbon targets.

Since detailed data on energy bills and household demographics are not publicly available, we use models based on geographic, demographic, housing-related, and climate variables to estimate household-level electricity and fuel use in a simulated portfolio of all residential buildings in Maryland (see **Appendix** for methods). Our analysis includes the most commonly used residential energy fuels in Maryland: natural gas, electricity, fuel oil, and propane. Using these estimates of household spending, we are able to aggregate households across Maryland, such as homes using natural gas for heating, and investigate trends in affordability across various types of households.

<https://www.psehealthyenergy.org/our-work/programs/clean-energy/western-states-deep-decarbonization/colorado/>

⁴⁴ Boris Lukanov, Arjun Makhijani, Karan Shetty, Yunus Kinkhabwala, Audrey Smith, and Elena Krieger. [Pathways to Energy Affordability in Colorado](#). (2022). PSE Healthy Energy.

Indicators of energy affordability are derived from these estimates of household income and annual energy costs as shown in **Figure 2-1a,b**.⁴⁵ One indicator used here is *energy cost burden*—the percentage of household income spent on residential energy needs. The median energy cost burdens within counties in Maryland are shown in **Figure 2-1c**.

As a metric, energy cost burden helps us compare energy affordability between different populations and is also a key indicator of energy insecurity, the inability of a household to meet their basic energy needs.⁴⁶ Typically, energy cost burdens in excess of six percent are considered high and present an undue strain on household finances.⁴⁷ This threshold leads to a secondary metric of affordability, the *energy affordability gap*: the total amount of money paid for energy bills in excess of six percent of a household's income.⁴⁸

The total affordability gap by county is mapped in **Figure 2-1d**. Counties with greater populations and greater energy cost burdens have larger affordability gaps. This metric helps to quantify the magnitude of the affordability problem and the associated opportunities to provide savings to ease household budgets. Combined, these two metrics serve to both target households in need and identify the financial extent by which homes are burdened.

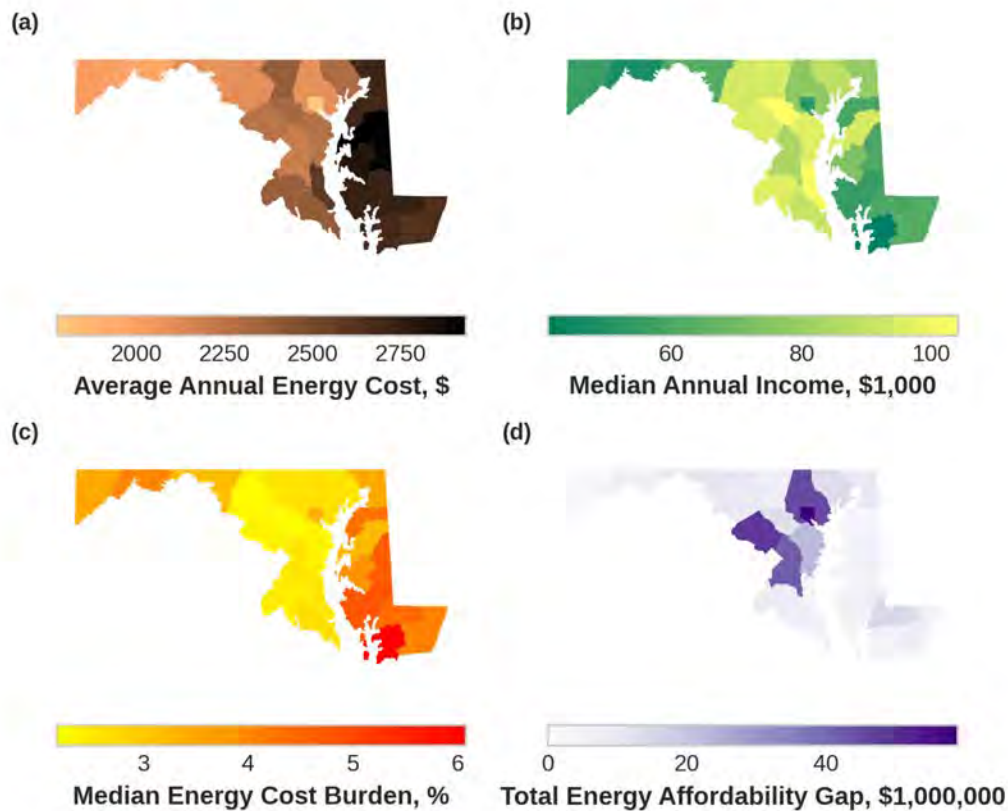
⁴⁵ All data regarding energy affordability rely on energy use and cost estimates generated for this report as described in the **Appendix**.

⁴⁶ Hernández D. (2013). Energy Insecurity: A Framework for Understanding Energy, the Built Environment, and Health Among Vulnerable Populations in the Context of Climate Change. *American Journal of Public Health*, 103(4), e32–e34. <https://doi.org/10.2105/AJPH.2012.301179>

⁴⁷ The federal Department of Housing and Urban Development defines affordable housing costs as 30 percent of income, including utility bills. Twenty percent of this amount—or six percent of income—is generally considered the affordability limit for energy bills. See Arjun Makhijani, Addressing Energy Burden: Estimate of Funds for Low- and Moderate-income Households during the Transition to a Clean, Regenerative, and Just Energy System, Just Solutions Collective, October 2021, p. 18 for discussion and references. At <https://ieer.org/wp/wp-content/uploads/2022/02/Addressing-Energy-Burden-Just-Solutions-Collective.pdf>

⁴⁸ Ibid.

Figure 2-1: Energy bill and income statistics for counties in Maryland aggregated from household scale estimates generated for this report.



Energy costs tend to be disproportionately higher for communities of color, even when controlling for household income.^{49,50,51} Systemic and structural inequities have contributed to this disparity between racial and ethnic groups, from federal government-sponsored segregation in housing, to redlining (refusing to insure mortgages in and around Black

⁴⁹ Kontokosta, C., V. Reina, and B. Bonczak. (2019). "Energy Cost Burdens for Low-Income and Minority Households." *Journal of the American Planning Association* 86 (1): 89–105.
doi.org/10.1080/01944363.2019.1647446

⁵⁰ Lyubich, E. (2020). "The Race Gap in Residential Energy Expenditures". *Energy Institute at HAAS*. WP-306

⁵¹ Krieger, E., Lukanov, B. et al. (2020). Equity-Focused Climate Strategies for New Mexico: Socioeconomic and Environmental Health Dimensions of Decarbonization. *Physicians, Scientists and Engineers for Healthy Energy (PSE)*.
<https://www.psehealthyenergy.org/our-work/programs/clean-energy/western-states-deep-decarbonization/new-mexico/>

neighborhoods).⁵² Such policies, as well as discriminatory lending practices, employment discrimination, and a legacy of segregated and underfunded schools, among other systemic barriers, have had massive impacts on economic and social inequality between racial groups that persist to this day.^{53,54,55} Because of such systemic exclusions, Black, Indigenous, and People of Color (BIPOC) communities also tend to live in less efficient and less healthy homes, and may experience higher costs when investing in energy efficiency upgrades.^{56,57,58} BIPOC and low-income households are more often renters, more often struggle to pay fluctuating bills, face the risk of utility shut-offs, and otherwise struggle with energy insecurity, which can exacerbate underlying health conditions and reduce resilience to climate extremes.⁵⁹

2.3 Energy Affordability in Baltimore City

Baltimore City presents challenges and opportunities that differ from less urban and rural areas in the rest of Maryland. First, low- and moderate-income (LMI) households in Baltimore City are more often renters, accounting for roughly 70 percent of households compared to 50 percent in the rest of Maryland. The type of housing in Baltimore City is also different. In Baltimore, LMI households mostly live in single attached homes such as row houses (47 percent) or multi-family structures (42 percent) with the remainder living in single detached homes (11 percent). For LMI households in the rest of Maryland, single attached homes are more rare (17 percent) while multi-family homes are still somewhat common (35 percent) and single detached homes much more common (45 percent) with the remaining households living in manufactured or mobile homes (3 percent). The increased percentage of renters living in multi-family or single attached structures in Baltimore City then influence the type of policies needed in order to bring down energy bills for these households.

⁵² Gross, T. (2017, May 3). A 'Forgotten History' Of How The U.S. Government Segregated America. <https://www.npr.org/2017/05/03/526655831/a-forgotten-history-of-how-the-u-s-government-segregate-d-america>

⁵³ Danyelle Solomon, C. M. (2019, August 7). Systematic Inequality and Economic Opportunity. <https://www.americanprogress.org/issues/race/reports/2019/08/07/472910/systematic-inequality-economic-opportunity/>

⁵⁴ Lombardo, C. (2019, February 26). Why White School Districts Have So Much More Money. <https://www.npr.org/2019/02/26/696794821/why-white-school-districts-have-so-much-more-money>

⁵⁵ Jargowsky, P. (2015). *Architecture of Segregation: Civil Unrest, the Concentration of Poverty, and Public Policy*. New York: The Century Foundation.

⁵⁶ Lewis, J., D. Hernandez, and A. Geronimus. (2019). "Energy Efficiency as Energy Justice: Address Racial Inequalities through Investments in People and Places." *Energy Efficiency*, 13, 419–32. doi.org/10.1007/s12053-019-09820-z.

⁵⁷ Reames, T. G. (2016). Targeting Energy Justice: Exploring Spatial, Racial/Ethnic and Socioeconomic Disparities in Urban Residential Heating Energy Efficiency. *Energy Policy*, 97, 549-558.

⁵⁸ Reames, T. G., Reiner, M. A., & Stacey, M. B. (2018). An Incandescent Truth: Disparities in Energy-Efficient Lighting Availability and Prices in an Urban U.S. County. *Applied Energy*, 218, 95-103.

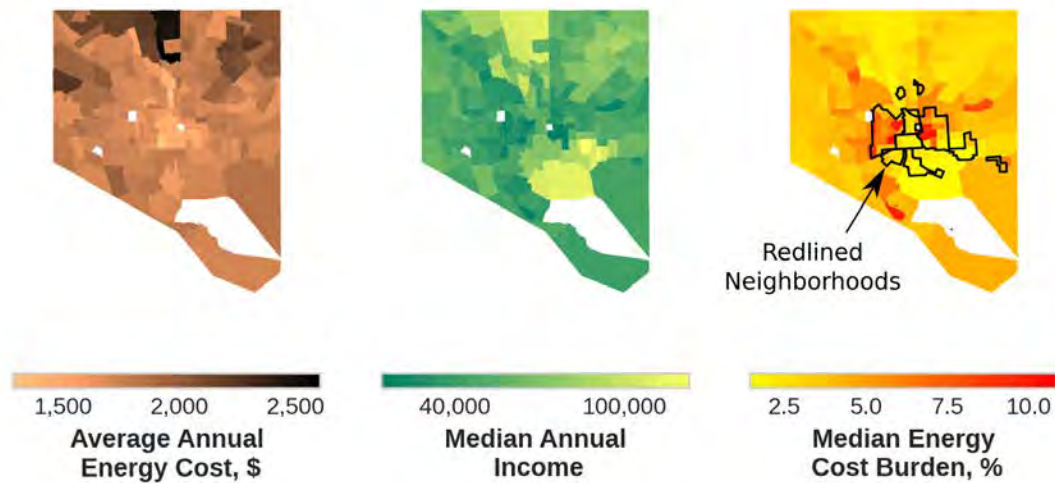
⁵⁹ The Race and Energy Nexus. (2021). *Pecan Street*. <https://www.pecanstreet.org/raceenergyxexus/>

Although energy bills for LMI households in Baltimore City are typically lower than the rest of Maryland, energy cost burdens remain high due to lower incomes. The lower energy bills in Baltimore are due in part to smaller home sizes that require less energy to heat or cool, and the use of piped natural gas, which enables the avoidance of more costly fuel oil or propane. For these reasons, the average LMI household's annual total energy usage and cost across all fuels in Baltimore is 69 MMBTU and \$1,700 as opposed to 75 MMBTU and \$2,070 in the rest of Maryland. However, incomes in Baltimore City are lower than surrounding counties. For example, Baltimore City's median annual income is \$54,000, significantly less than \$91,000 for Maryland as a whole.⁶⁰ Additionally, while Baltimore City only contains roughly 11 percent of Maryland's households, it is home to 19 percent of Maryland's LMI households.

Fine-grained, census-tract-level maps in **Figure 2-2** demonstrate that affordability challenges are not uniformly distributed across Baltimore City but are concentrated in certain neighborhoods. The neighborhoods with the highest energy cost burdens historically have also been the most disadvantaged, due in part to policies such as redlining, which disproportionately affected BIPOC households. The median incomes for BIPOC households in Baltimore City, which represent roughly 70 percent of households in the city, is only \$44,000, as compared to \$78,000 for households categorized as non-Hispanic White. These inequities result in a disproportionate amount of Maryland's energy affordability challenge lying in Baltimore City and, more specifically, its historically disadvantaged populations.

⁶⁰ Baltimore City and Maryland Quick Census Facts 2017-2021; at <https://www.census.gov/quickfacts/baltimorecitymaryland> and <https://www.census.gov/quickfacts/fact/table/MD/PST045221>

Figure 2-2: Energy bill, income statistics, and energy cost burden indicators for census tracts in Baltimore City. “Redlined neighborhoods” outlined in black received the lowest score by the Home Owners’ Loan Corporation.⁶¹

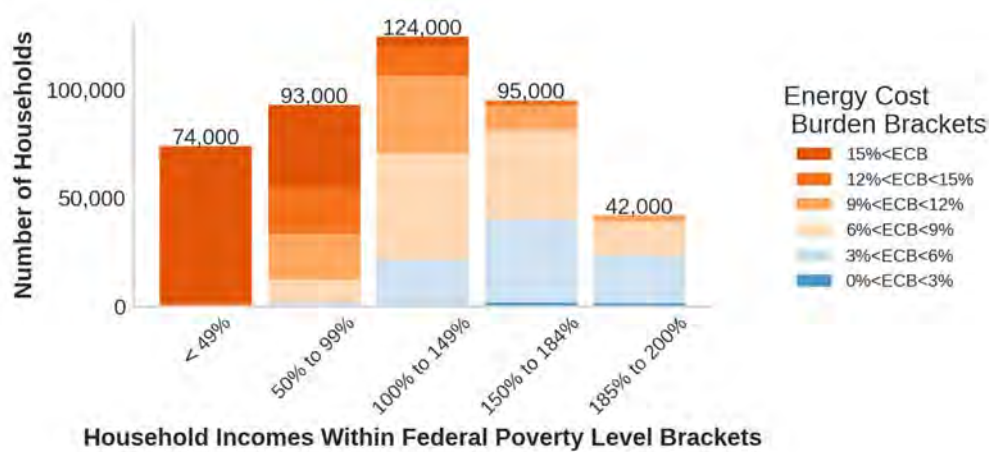


2.4 Energy Cost Burdens by Income

Income inequality is the primary driver of differences in energy cost burdens. While 80 percent of households earning less than twice the federal poverty level are energy cost-burdened, only 3 percent of households greater than twice the federal poverty level are energy cost-burdened. For this reason, we focus primarily on the 20 percent of Maryland’s households with incomes less than twice the federal poverty level who we categorize as LMI. In **Figure 2-3**, we plot the energy cost burden distribution of households within federal poverty level-derived income brackets. We see here that practically all households earning less than the 100 percent of the federal poverty level in Maryland have energy cost burdens that exceed the six percent threshold. As expected, higher income households are less burdened.

⁶¹ Mapping Inequality: Redlining in New Deal America.
<https://dsl.richmond.edu/panorama/redlining/#loc=11/39.293/-76.79&city=baltimore-md&area=B1>

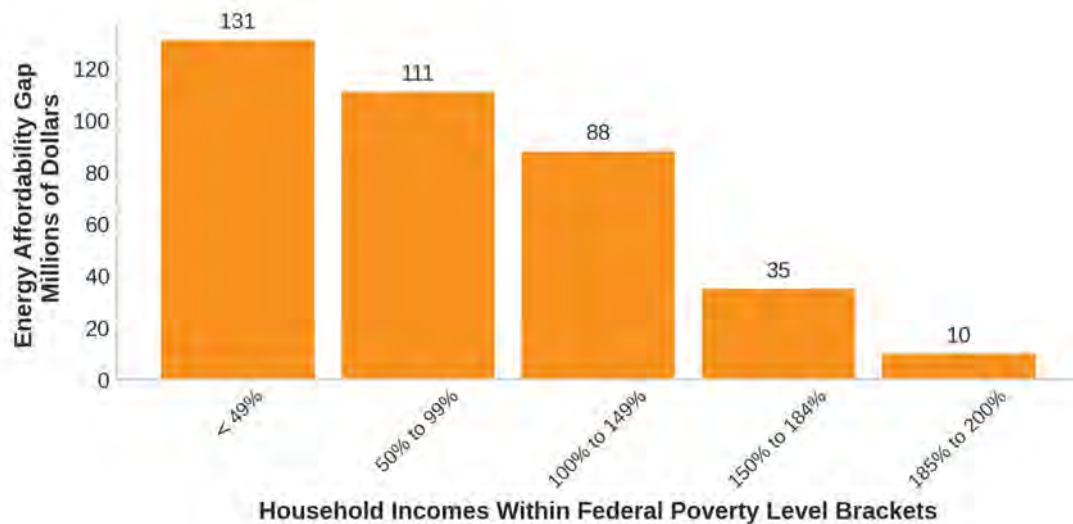
Figure 2-3: Number of households within federal poverty level brackets broken down by energy cost burden (ECB). Not shown in the figure are ~50,000 households with income above 200 percent of federal poverty level and cost burdens greater than six percent.



Energy cost burdens capture the relative burden for a household, but do not directly represent the cumulative magnitude of the financial challenge statewide, which is better captured by the energy affordability gap metric shown in **Figure 2-3**. The total estimated annual energy affordability gap for 2021 in Maryland is roughly \$400 million.⁶² The gap is highest for the lowest income bracket despite the fact that the number of households in this bracket is comparatively low. This is due to the fact that, on average, a greater proportion of the lowest income households' energy bills must be paid down in order to reach the six percent threshold. This sum, then, represents the total annual funds needed in the form of bill assistance to ensure that no household spends more than six percent of their income on their energy needs. There are also roughly 50,000 households with incomes above 200 percent of the federal poverty level who have energy cost burdens greater than six percent. In these cases, they are generally only slightly above six percent. Our estimate of the affordability gap of \$400 million includes these households (not shown in Figure 2-3).

⁶² Fisher, Sheehan, and Colton have previously estimated \$708 million for this gap. Differences in estimates of energy affordability gaps are discussed in the **Appendix**. We have adjusted our estimate of \$350 million upward to \$400 million to account for the somewhat lower energy use estimates that our method produces compared to official data. See the **Appendix**.

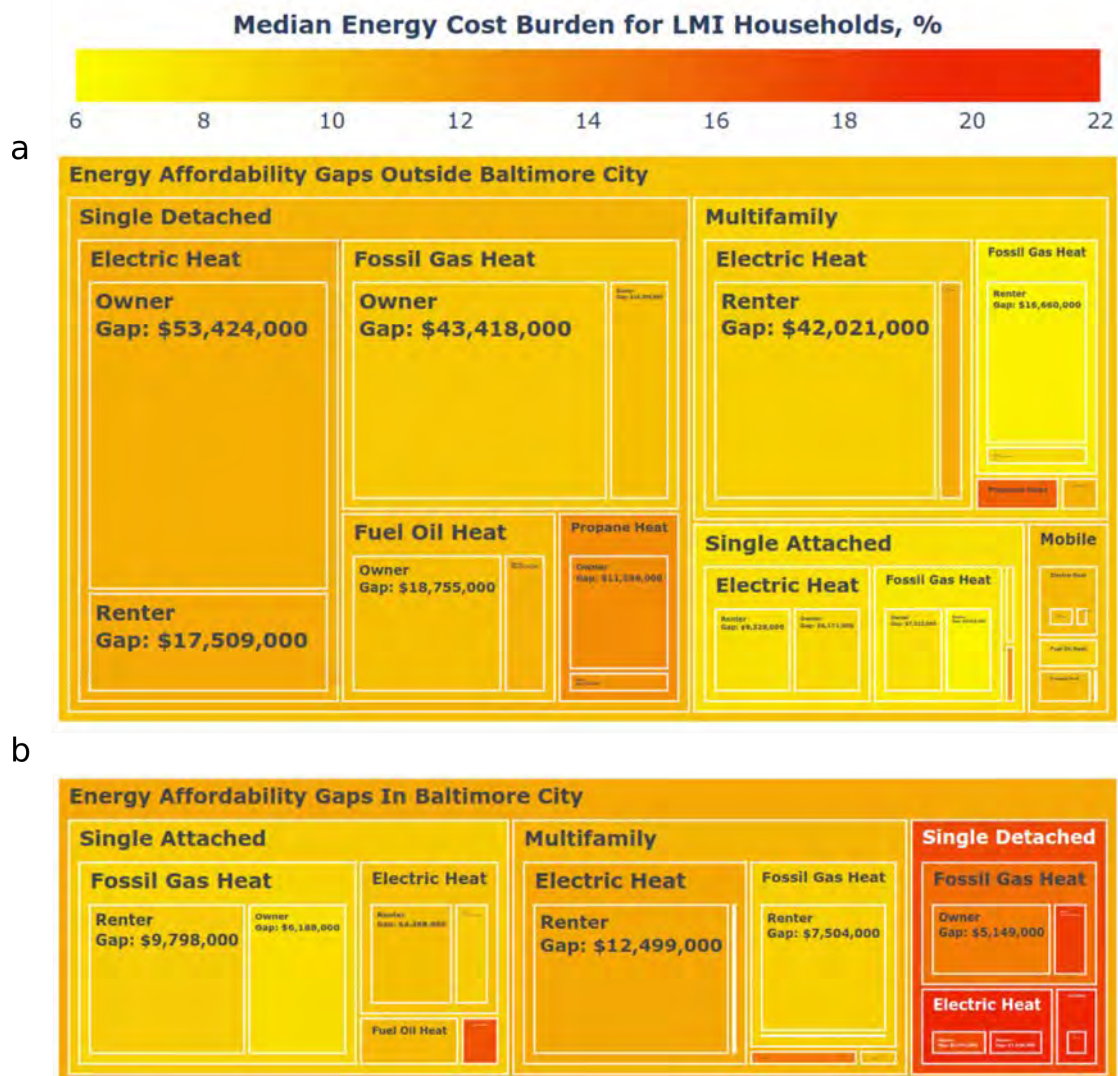
Figure 2-3: Total energy affordability gap within income groups defined by the federal poverty level



2.5 Energy Cost Burden Analysis

We see significant variations in energy affordability that are driven by a variety of factors, which function together to increase or decrease a household's burden in complicated ways. Here, we identify populations that may benefit most from targeted interventions by grouping together households according to their location, type of heating fuel, type of home, and whether they rent or own their home. In **Figure 2-4**, we summarize the affordability indicators for LMI households broken down by these categories. Areas of rectangles in this figure are proportional to affordability gaps while their shading indicates the median cost burdens thus representing the interplay between these two indicators. For example, single detached homes outside of Baltimore City heated by propane have higher cost burdens than homes heated by gas indicated by the redder color in the figure, but propane-heated homes have a smaller *overall* gap—indicated by the size of the rectangle—than gas-heated homes, since those homes are less common. Importantly, since this figure only considers LMI households, it does not represent the differences seen within the entire population. For example, in Baltimore City, the energy cost burden for just LMI households in single detached homes is the highest among the different home types due to larger average bills as shown in **Figure 2-4b**, but the average burden for all households in Baltimore City in single detached homes is actually the smallest since the median income for such households is much higher. In the following sections, we investigate the causes for the trends shown here.

Figure 2-4: Treemap of the breakdown of the total energy affordability gap for LMI households **(a)** outside Baltimore City and **(b)** in Baltimore city categorized by home type, fuel used for space heating, and renter versus owner-occupied status. Color shading indicates the median energy cost burden and the size of the rectangles are proportional to the total energy affordability gap for each subset of households.



2.5.1 Energy Cost Burdens by Fuel Type

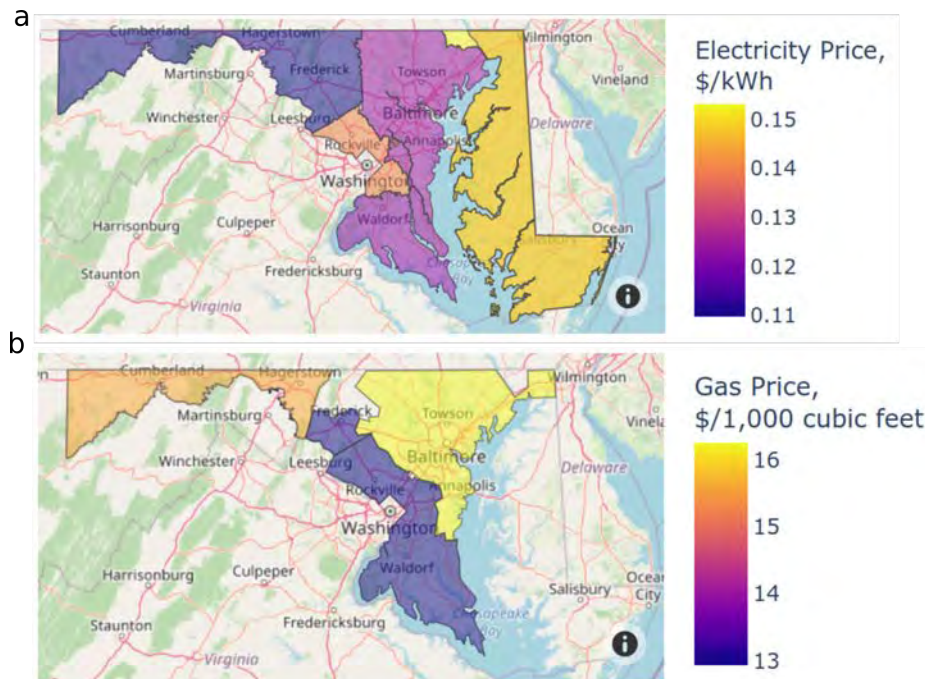
The type of fuel used for water and space heating strongly influences overall energy bills due to significant differences in rates charged for each fuel. In this chapter, we only consider the financial impacts of residential consumer rates for each of these fuels and reserve discussion of the health, safety, reliability, and climate impacts of these different fuels in the following chapters. **Table 2-1** summarizes the average rates for each of these different fuels for the year 2021. Moreover, for natural gas and electricity, we use rates specific to the largest utility service areas shown in the maps in **Figure 2-5**.

Table 2-1: Average 2021 rates for different fuels used across Maryland.

Fuel Type	Average rate across Maryland in 2020, Dollars per MM BTU ⁶³
Electricity	\$39.20 excluding retail choice (\$0.134/kWh)
Fossil Gas	\$14.50 excluding retail choice (\$1.45/therm)
Propane	\$27.79
Fuel Oil	\$18.43
Wood	\$7.04

⁶³ Average electric and natural gas rates for utilities were estimated by dividing revenue by sales as reported by the EIA in forms EIA-861 (<https://www.eia.gov/electricity/data/eia861/>) and EIA-176 (<https://www.eia.gov/naturalgas/ngqs/#?report=RPC&year1=2018&year2=2021&company=Name>) respectively and then averaged by total number of customers. Rates for other fuels were obtained from the EIA State Energy Data System. https://www.eia.gov/state/seds/data.php?incfile=/state/seds/sep_sum/html/sum_btu_res.html&sid=US

Figure 2-5: Average annual prices from 2021 for (a) the six largest bundled electricity utilities and (b) the three largest natural gas , excluding impacts from retail choice marketers.⁶⁴



As of 2021, natural gas was the most affordable fuel per unit energy (other than wood), propane was the most expensive fossil fuel, and electricity the most expensive per unit energy. However, comparison of fuels based on cost per unit energy does not provide the full picture. Although electricity has a higher cost per unit of energy delivered, using electrically-powered efficient heat pump technology can drastically reduce the total energy needed to heat a home and, for most homes, can provide the lowest energy bills. **Figure 2-6** plots the expected savings in annual energy bills for homes when outfitted with efficient heat pumps.⁶⁵ These findings are in line with other related studies.⁶⁶ We assume conversion to an efficient heat pump results in average annual heating energy savings of 72 percent, which corresponds to a heat pump seasonal coefficient of performance (SCOP) value of 3.0 replacing

⁶⁴ Prices were estimated by dividing total residential revenue by total residential sales for each utility as reported to the EIA for 2021 in forms EIA-861 and EIA-176 for electricity and natural gas respectively.

⁶⁵ These costs exclude conversion costs and only considers usage. Incorporation of conversion costs is discussed in **Chapter 5**.

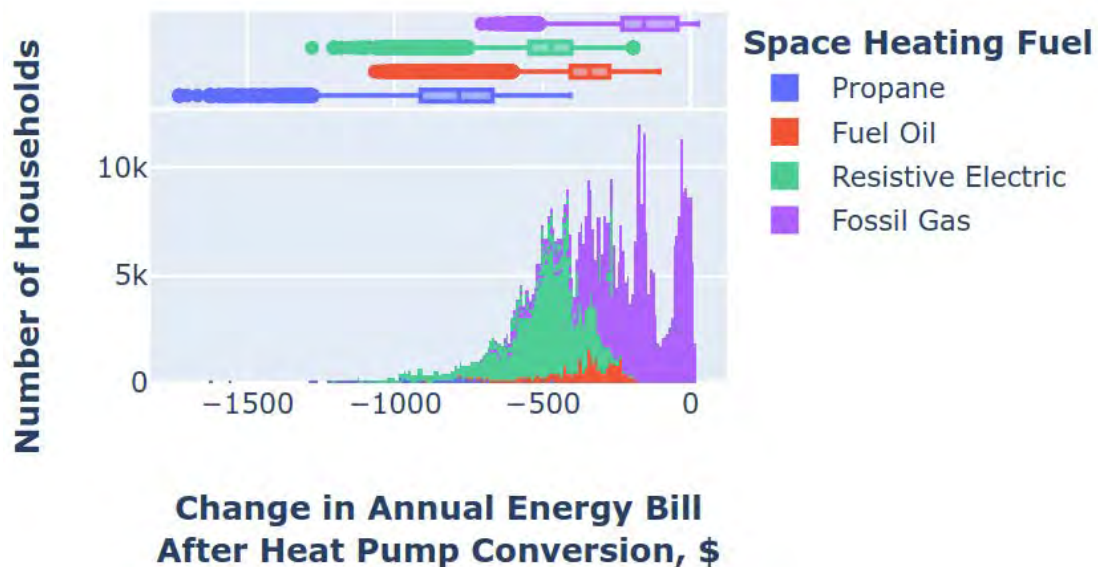
⁶⁶ Deetjen, T. A., Walsh, L., & Vaishnav, P. (2021). U.S. residential heat pumps: the private economic potential and its emissions, health, and grid impacts. *Environmental Research Letters*, 16(8), 084024.

older thermal heating sources with efficiencies of 80 percent.⁶⁷ Most new residential construction already relies on efficient electric heat pump technology due to their many benefits. For example, using rates for the year 2021 shown in **Figure 2-5**, nearly all homes experience energy bill savings when the cost of conversion is excluded. If we group households by their current space heating fuel, we find average annual savings of \$150, \$352, \$780, and \$476 for natural gas, fuel oil, propane, and electric resistive heating respectively. We assume here that, at present, existing heat pumps are primarily in detached homes while homes in multi-family structures use electric resistance heating. The amount a natural gas-using household saves is highly dependent on the local rates and climate. Geographically, the savings are greatest where electricity is cheap and natural gas is expensive (see **Figure 2-5**) such as Western Maryland. Savings are lowest in Montgomery and Prince George's Counties where the opposite was true in 2021. However, the price of natural gas fluctuates substantially, which leads to significant uncertainty regarding expected savings over time. A recent report for Maryland⁶⁸ cited that conversion to heat pumps are economic (NPV>0) for only 20 percent of natural gas heated homes in the year 2019; however, using rates from 2021 and funding available from the Inflation Reduction Act for LMI households discussed in **Chapter 5**, we see that value shift to greater than 90 percent. With improvements in heat pump technology, expected increases in residential natural gas prices discussed in **Chapter 4**, and a warming shift in climate, the annual savings provided by electric heat pumps are only expected to increase.

⁶⁷<https://mde.maryland.gov/programs/Air/ClimateChange/MCCC/MWG/Decarbonizing%20Buildings%20in%20Maryland.pdf>. Table 3. We assume that, in general, home heating will be electrified when the furnace or boiler would otherwise be replaced.

⁶⁸ Ibid. Reported on page 13, cited from Mayernik, J. Cost Effectiveness of Electrification with Air-Source Heat Pumps. Presentation to the Maryland Commission on Climate Change's Buildings Subgroup. August 2020.

Figure 2-6: Changes in annual energy bill after conversion to electric heat pumps broken down by fuel type at 2021 rates.



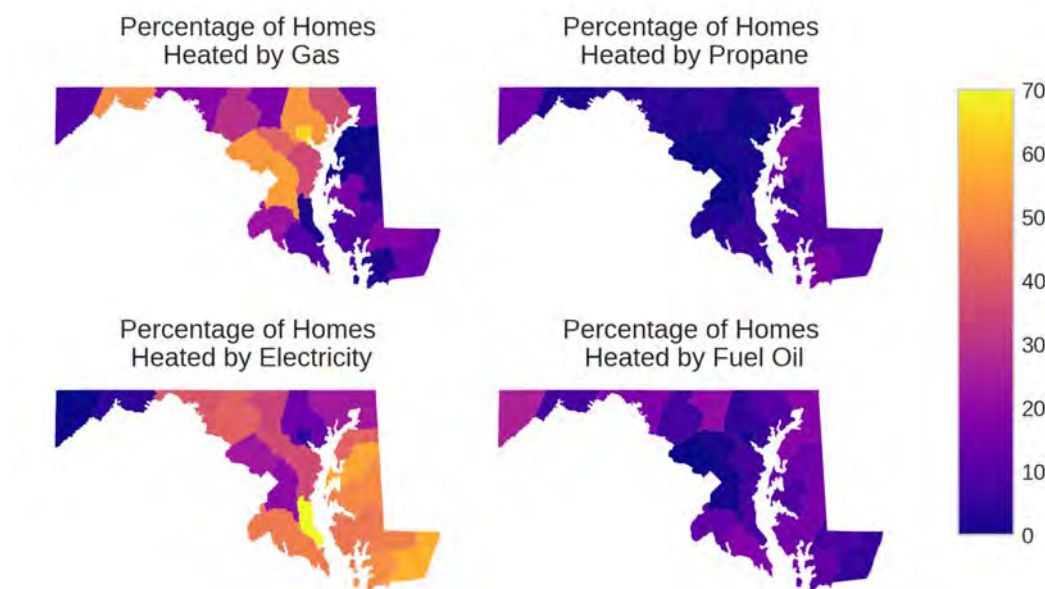
Importantly, the above comparison of heat pumps with other heating technologies excludes many of the additional benefits of electrification. For example: space cooling from high-end heat pumps is more efficient on average than conventional air conditioners thus providing savings in the summer; indoor humidity is better controlled with heat pumps providing cleaner and healthier indoor air in humid environments; retirement of indoor fossil fuel use improves indoor air quality as discussed in **Chapter 3**; heat pumps provide space cooling that many homes currently lack—but which they will increasingly need as the climate warms; and heating with heat pumps instead of fossil fuels reduces the overall climate impacts of heating.⁶⁹

Geographic differences in affordability are largely driven by fuel choice shown in **Figure 2-7**. Since space heating is the largest end use for residential energy consumption, we use the fuel chosen for space heating to characterize homes even though appliances and water heaters may use different fuels. Where piped natural gas is available, typically in more urban areas, it

⁶⁹ IEA, Relative CO2 emissions from the operation of air-source heat pumps compared with the most efficient condensing gas boilers by region in the Net Zero Scenario, 2010-2030, IEA, Paris
<https://www.iea.org/data-and-statistics/charts/relative-co2-emissions-from-the-operation-of-air-source-heat-pumps-compared-with-the-most-efficient-condensing-gas-boilers-by-region-in-the-net-zero-scenario-2010-2030>, IEA. Licence: CC BY 4.0

is the most common heating fuel. In geographies with milder winters along the eastern coast of Maryland, there is limited natural gas service and relatively more usage of the more costly fuels—fuel oil and propane. The different penetrations of fuels contribute to the surprising effect that, although the *total* energy used for heating is lower in the milder winters along the Eastern Shore, household bills are not as low as would be expected because the fuels used are more expensive (see **Figure 2-1a**).

Figure 2-7: Percentage of homes by county using the four most common fuels for home heating.



In addition to the fuels described above, less common fuels used in Maryland include wood and coal, with the coal heated homes almost exclusively found in Garrett County. Prices for these fuels are difficult to estimate accurately. For example, some wood-burning homes collect their own wood from their own land. While such homes are more exposed to indoor air pollutants than electrically-heated homes, it is difficult to estimate their energy bills.

2.5.2 Home Type and Renter Status

Home type is another strong indicator of energy affordability challenges. The U.S. Census categorizes homes into the following: detached single-family houses, attached single-family houses (e.g. row homes), apartments in buildings with 2-4 units, apartments in buildings with five or more units, and mobile homes. Here, we group all apartments into multi-family units with the remainder being single-family homes. Factors such as geographical location, fuel

types, income of habitants, and size drive energy affordability differences between these homes. We discuss the significant trends between home types shown in **Figure 2-4** above and present detailed breakdowns based on fuel use for space heating, energy bills, and ownership status in **Table 2-2**.

Table 2-2: Statistics of energy cost and affordability gap for all Maryland households broken down by home type.

Home Type	Average Annual Energy Cost, \$	Median Annual Income, \$	Median Energy Cost Burden, %	Total Gap, Million \$	Percent of Gap Renter Occupied
Single Detached Home	\$2,617	\$99,000	2.6%	\$196 M	21%
Single Attached Home	\$1,886	\$80,000	2.3%	\$58 M	55%
Multifamily w/ 2-4 Units	\$1,667	\$42,000	3.8%	\$18 M	93%
Multifamily w/ 5+ Units	\$1,654	\$58,000	2.8%	\$74 M	90%
Mobile Home	\$2,162	\$44,000	4.8%	\$9 M	30%

Across Maryland, 55 percent of the total affordability gap is concentrated in single detached homes despite the fact that only 39 percent of LMI households live in single detached homes. This is driven in part by low-income households with high energy bills in rural areas. These single detached homes also disproportionately use more expensive fuels for heating. The average energy bill for just the LMI households in single detached homes is \$2,350 compared with \$1,910 for all LMI households. These homes are also typically owner-occupied, and these owner-occupied homes account for 79 percent of the single detached home affordability gap.

In multifamily housing, however, 90 percent of the energy affordability gap for LMI households is in renter-occupied homes. These homes are primarily found in urban areas of Maryland. Specifically, 57 percent of the gap from multi-family homes is found in Baltimore City (23 percent), Prince George's County (15 percent), and Montgomery County (19 percent) with the latter two counties representing closer-in suburbs of Washington, D.C. In these homes, 95 percent of the gap is found in homes heated by electricity or natural gas.

Single attached homes (or rowhouses) share trends that lie somewhere between apartments and single detached homes. They are more often owner-occupied than apartments but less so than detached homes.

Mobile homes are a less common but unique subset of homes in Maryland. While approximately 1.2 percent of all Marylanders live in mobile homes, that number rises to 2.5 percent for LMI households, representing also 2.5 percent of the total affordability gap. They also have a median cost burden of 4.8 percent, the highest of the home types considered here. Although heating needs are typically lower for these homes given their smaller floor area, they tend to pay outsize bills due to poorer insulation and their increased reliance on propane or fuel oil for space heating. These two fuels account for 23 percent and 22 percent of the mobile home affordability gap respectively; these homes are most likely to benefit from fuel switching to efficient electric heat pumps.

2.5.3 Race and Ethnicity

Disadvantaged racial groups on average experience greater degrees of energy poverty. The primary cause is due to severe income inequality between racial groups. The median household incomes for Maryland households identifying as White, Hispanic, and Black, are roughly \$90,000, \$75,000, and \$70,000 respectively, with corresponding median energy cost burdens of 2.5, 2.9, and 2.9 percent. However, this disparity dramatically increases in certain geographical areas. In Baltimore City, while the median energy cost burden is only 2.2 percent for White households, it is 3.0 percent for Hispanic households, and increases to 4.0 percent for Black households, reflecting a racial income gap, among other factors.

The disparities described above between racial groups are primarily driven by income inequality, but do not fully capture additional disparities that may exist due to differences in cost. Studies⁷⁰ have shown using fine scale raw data that historically disadvantaged racial groups still experience even greater energy cost burdens often due to inhabiting less efficient homes (which in turn may be related to historical inequities). Due to insufficient data specific to Maryland to predict differences in efficiency between households of different racial groups, we do not fully account for the disparities in energy efficiency and thus expect that energy cost burdens for historically disadvantaged groups are likely even higher than the values presented here.

⁷⁰ Tong, Kangkang, et al. "Measuring social equity in urban energy use and interventions using fine-scale data." *Proceedings of the National Academy of Sciences* 118.24 (2021): e2023554118.

2.5.4 Utility Type

Maryland customers are served by three kinds of electric utilities: investor-owned (89 percent of households), cooperative (10 percent), and municipal (1 percent). While electricity and gas rates are similar across the three utility types, total energy costs in areas served by coops tend to be higher largely because of the higher prevalence of fuel oil and propane as heating fuels. Coops also have a larger fraction of detached homes which have greater heat losses per unit area than multi-family structures. Electricity costs depend on whether the home is electrically heated and, if so, on the type, and quality, of structure.

Beyond the regulated bundled utility services shown above, Maryland households also have the option to choose an alternative energy supplier for electricity or natural gas. Third party suppliers acquire electricity and natural gas on the deregulated wholesale markets and deliver them to retail customers via the regulated electricity and natural gas distributed infrastructure. Customers pay for the electricity and natural gas commodity costs as charged by third party suppliers, and for distribution and other costs, such as taxes and monthly connection charges, they pay the regulated rates. Retail choice served roughly 404,000 residential customers in 2021, or 17.6 percent of all Maryland households, from 42 different retail supplier companies. Regulated retail electricity supply rates, with the energy commodity (electricity or natural gas) bundled with the distribution costs, varied in 2021 from \$0.08 to \$0.14 per kWh. While customer geographical data is not available for each third-party retail energy supplier, we calculate that retail choice electricity residential accounts paid more, on average, than electricity customers who choose Standard Offer Service.

For example, in 2021, the statewide weighted average delivery and supply electricity rate for the bundled regulated customers was approximately \$0.128 per kWh. All Maryland utility residential customers paid a weighted average delivery rate of \$0.056 per kWh, regardless of which entity supplied their electricity. Maryland's weighted average third party electricity supply rate in 2021 was \$0.10 per kWh compared to regulated utility rate of \$0.072 per kWh. While regulated customers paid all-in \$0.128 per kWh, 404,000 retail choice energy customers rates averaged 22 percent more: all-in \$0.156 per kWh, resulting in an average of \$291 more per account. For this reason, retail choice households spend more on energy on average than households on Standard Offer Service supply. Assistance provided to low- and moderate-income households who are on third party supply is less effective in reducing energy cost burdens because, in effect, some of the assistance just flows to third party suppliers to pay the excess costs, rather than reducing the energy cost burden. For example, a household with an income of \$20,000 and an energy cost burden of 10 percent would see their burden reduced to 7.5 percent with assistance of \$500; a typical third party supply rate would

increase the cost by about \$300, and the burden to 11.5 percent. The same assistance would leave the households with a post-assistance cost burden of 9 percent.

Detailed data on demographics regarding who is more impacted by retail power marketing companies is not available. In order to incorporate these rates into the dataset presented here, we randomly assigned homes to retail choice companies according to the number of delivery-only customers reported by utilities within their respective service areas. Alongside the local delivery rate, we added a weighted average wholesale electricity rate of \$0.10 per kWh for these retail choice customers. Incorporating retail choice for the fraction of households that are low- and moderate-income on a proportional basis resulted in an increase of the total affordability gap by \$30 million as compared to a scenario in which all households would have used their standard offer service for electricity. Moreover, given that customers of retail power marketing are often low-income customers, we performed a sensitivity analysis in which only households earning less than four times the federal poverty level (roughly half of all households) were customers of retail power marketing. This increased the total affordability gap for electricity by \$30 million.

Retail choice is also available for natural gas customers. Data for rates for these utilities are even less transparent than for retail choice for electricity consumers. We do know that 200,000 customers belong to retail choice for their natural gas. A conservative estimate from a survey of energy bills is that retail choice adds an additional \$2.50 per MMBTU to rates, approximately a 17 percent increase. This adds about \$7 million to natural gas bills of LMI households.

Overall, the impact of third party supply on LMI energy bills for third-party electricity and gas rates above standard offer service is about \$40 million.

2.6 Additional Considerations for Energy Affordability

2.6.1 Changes in Natural Gas Prices

Energy bills depend on energy rates and rate structures. Thus far, our analysis has assumed rates approximated from the year 2021⁷¹ shown in **Table 2-1**. However, rates can change, especially for natural gas. It is therefore important to investigate how historic and projected rates impact affordability.

⁷¹ As reported in EIA forms EIA-861 and EIA-176 and EIA State Profiles and Energy Estimates.
https://www.eia.gov/state/seds/data.php?incfile=/state/seds/sep_sum/html/sum_btu_res.html&sid=US

The highly variable price of natural gas can lead to drastic changes in energy affordability. While actual natural gas prices for BG&E increased 15 percent between 2018 and another 7 percent from 2020 to 2021, real electricity prices have changed by less than 5 percent in all since 2012. Increases in the price of natural gas are responsible for increased median energy cost burdens for fossil gas reliant LMI households by 0.7 percent (from 7.8 to 8.5 percent) just over the three-year period from 2018 to 2021 alone. Moreover, while data for the year 2022 are not yet available, we note that BG&E commodity prices for natural gas are thus far 60 percent higher than in 2021 using data from the months of January-October, suggesting even larger impacts from turbulent fossil gas prices may already be underway. We note that this analysis only accounted for the change in gas prices and not the resulting, but proportionally smaller, increase in electricity prices associated with the increase in gas prices. Prices for electricity are more stable than natural gas due to electricity's dependence on a wide variety of technologies and the smaller fraction that fuel cost typically plays in total electricity cost. Finally, in **Chapter 4** we show that gas prices could skyrocket in the 2030s if the present direction of continued investments in gas infrastructure is allowed to persist.

2.6.2 Homes with Very High Energy Use

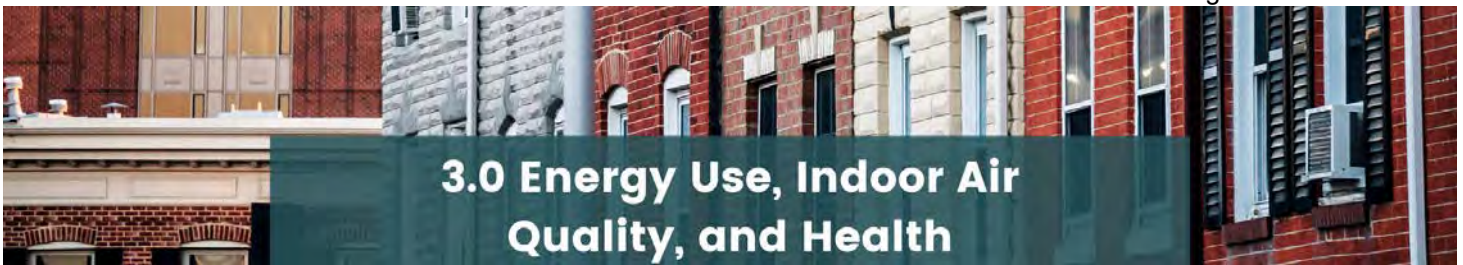
Our findings thus far are based on models that estimate typical energy usages for homes and thus tend to omit outlier homes that use far more or far less energy than found in our estimates. One source for such data is the Office of Home Energy Programs (OHEP) which released annual electricity usage for surveyed LMI homes in the year 2014. While the average LMI household electricity consumption for estimates in this report is comparable to the average usage from the report, 11,300 kWh/year and 11,900 kWh/year respectively, there are significant outlier homes within the OHEP dataset that consumed much more than average. For example, while we estimate that only 2 percent of households use more than 25,000 kWh/year, the OHEP dataset triples that value to 6 percent. If these homes with exceptionally high usage were incorporated into our estimates, we would expect a significant increase of the energy affordability gap. Low-income households with very high usage such as these have the most potential for savings and would greatly benefit from interventions that improve efficiency.

2.7 Summary

Energy bills for the majority of LMI households in Maryland cause an undue financial burden. This burden is more acute in households using more expensive fuels such as propane and fuel oil. The buildings where LMI households live are also typically less efficient. There are large

concentrations of households strained by energy bills due to concentrated poverty in urban areas including Baltimore City and some areas surrounding DC, where multifamily renter-occupied housing is more common.

In homes that have natural gas appliances, high energy cost burdens are accompanied by health-damaging indoor air pollution caused by burning gas, a topic explored further in **Chapter 3** below.



3.1 Introduction

People in the United States spend more than 80 percent of their time indoors.⁷² Given this simple fact, policies shaping indoor environments—such as new building construction or retrofit standards—can have significant impacts on quality of life and public health.

In Maryland, 8.3 percent of energy-related greenhouse gas emissions come from burning fossil fuels in residential buildings for space and water heating and appliances.⁷³ In addition to releasing greenhouse gases, fuel combustion and use in homes produces health-damaging air pollutants, which can contribute to poor indoor air quality. State climate policy currently promotes reduction of these emissions through energy efficiency and by transitioning to cleaner sources of fuel and energy. By taking a holistic approach, Maryland can ensure these policies also improve public health by reducing indoor air pollutant emissions and ensuring that upgrades to improve building efficiency incorporate measures, such as proper ventilation, that can improve indoor air quality.

In this chapter, we summarize current scientific understanding on the impacts of energy use and retrofits on air quality and public health. An overview of our methods is included in the **Appendix**. In **Section 3.2**, we summarize the influence of indoor air quality on human health and describe populations particularly vulnerable to indoor air pollution. In **Section 3.3**, we assess the potential impacts of household fuel type on indoor air quality and health, focusing specifically on combustion sources. In **Section 3.4**, we summarize the impacts on indoor air quality of healthy homes programs; low-carbon retrofits; and household interventions intended to improve energy efficiency, ventilation, and/or to decarbonize (e.g., weatherization, electrification). Where available, we highlight the relevance of study findings for the residents of Maryland and Baltimore City.

⁷² Klepeis, N. E., Nelson, W. C., Ott, W. R., Robinson, J. P., Tsang, A. M., Switzer, P., Behar, J. V., Hern, S. C., & Engelmann, W. H. (2001). The National Human Activity Pattern Survey (NHAPS): A resource for assessing exposure to environmental pollutants. *Journal of Exposure Analysis and Environmental Epidemiology*, 11(3), 231–252. <https://doi.org/10.1038/sj.jea.7500165>

⁷³ Derived from Maryland Department of Environment 2022. Maryland 2020 Greenhouse Gas Inventory, November 24, 2022, at https://mde.maryland.gov/programs/air/ClimateChange/Documents/VIMAL/MD_2020_GHG_Inventory_2022-09-24.xlsx Does not include indoor leaks of natural gas as methane.

KEY FINDINGS

- Weatherization, electrification, and ventilation can be combined to improve both energy efficiency and indoor air quality, resulting in simultaneous benefits for climate and public health.
- Energy cost burdens can be greatly reduced by a combination of weatherization, efficient electrification, and discounted community solar electricity supply.
- Energy efficiency and decarbonization-related interventions that improve indoor air quality should be prioritized, particularly within vulnerable populations.

3.2 Indoor Air Quality and Health

Indoor air quality in residential settings is impacted by biological (e.g., mold, allergens), chemical (e.g., gaseous combustion emissions from gas appliances), and physical (e.g., ventilation, insulation) factors.⁷⁴ Indoor air pollution represents a mix of hundreds to thousands of gas and particle phase compounds, the levels and types of which are influenced by the air exchange rate of the home, which in turn is modified by the size of the home, the household's heating, ventilation, and air conditioning (HVAC) system, localized ventilation systems (e.g., presence of a hood fan over the stove), and the permeability of the home (e.g., presence of cracks or gaps).

In multifamily housing (i.e. apartments, attached townhouses, and condos), indoor air pollutants can influence indoor air quality in neighboring units.⁷⁵ Outdoor pollution may also influence indoor air quality if it enters the home through the HVAC system or unintentional cracks or openings.⁷⁶ Indoor particulate matter (PM) levels in the home, for example, are influenced by outdoor sources as well as indoor activities, including cooking, fireplace use,

⁷⁴ Weitzman, M., Baten, A., Rosenthal, D. G., Hoshino, R., Tohn, E., & Jacobs, D. E. (2013). Housing and Child Health. *Current Problems in Pediatric and Adolescent Health Care*, 43(8), 187–224. <https://doi.org/10.1016/j.cppeds.2013.06.001>

⁷⁵ U.S. EPA. (2017). Indoor Air Quality in Multifamily Housing [Overviews and Factsheets]. <https://www.epa.gov/indoor-air-quality-iaq/indoor-air-quality-multifamily-housing>

⁷⁶ Zhang, L., Ou, C., Magana-Arachchi, D., Vithanage, M., Vanka, K. S., Palanisami, T., Masakorala, K., Wijesekara, H., Yan, Y., Bolan, N., & Kirkham, M. B. (2021). Indoor Particulate Matter in Urban Households: Sources, Pathways, Characteristics, Health Effects, and Exposure Mitigation. *International Journal of Environmental Research and Public Health*, 18(21), 11055. <https://doi.org/10.3390/ijerph182111055>

smoking, fuel combustion for heating, and burning candles and incense.⁷⁷

Poor indoor air can substantially impact human health, especially for populations that are most vulnerable (e.g., low income households, people of color, pregnant people, children, older adults, and those with chronic respiratory conditions such as asthma).^{78,79} Poor indoor air is a major driver of respiratory, cardiovascular, and neurological health and can adversely impact pregnancy outcomes. Energy-related emissions can influence indoor air quality through a variety of factors including but not limited to: the type, quality, and number of appliances in use; household fuel activities (e.g., cooking, heating); and fuel type used (e.g., natural gas, biomass, electricity). Other factors that can help mitigate the impact of poor indoor air include activities such as opening a window or using a fan for ventilation; household characteristics (e.g., size, layout, and presence of HVAC); and reducing how much time people spend in their home.^{80, 81}

Certain populations are at higher risk from air pollution. For instance, low-income populations and people of color, and especially children, are disproportionately exposed to environmental housing hazards and have higher rates of asthma.^{82,83} Renters also frequently lack the financial means or freedom to implement interventions to improve air quality in the home. Populations with underlying health conditions (e.g., lung disease) have increased

⁷⁷ Ibid.

⁷⁸ Krieger, J. W., Takaro, T. K., & Rabkin, J. C. (2011). Breathing Easier in Seattle: Addressing Asthma Disparities Through Healthier Housing. In R. A. Williams (Ed.), *Healthcare Disparities at the Crossroads with Healthcare Reform* (pp. 359–383). Springer US. https://doi.org/10.1007/978-1-4419-7136-4_19

⁷⁹ Phillips, T. J., & Levin, H. (2015). Indoor environmental quality research needs for low-energy homes. *Science and Technology for the Built Environment*, 21(1), 80–90. <https://doi.org/10.1080/10789669.2014.975056>

⁸⁰ Fisk, W. J., Singer, B. C., & Chan, W. R. (2020). Association of residential energy efficiency retrofits with indoor environmental quality, comfort, and health: A review of empirical data. *Building and Environment*, 180, 107067. <https://doi.org/10.1016/j.buildenv.2020.107067>

⁸¹ Zhang, L., Ou, C., Magana-Arachchi, D., Vithanage, M., Vanka, K. S., Palanisami, T., Masakorala, K., Wijesekara, H., Yan, Y., Bolan, N., & Kirkham, M. B. (2021). Indoor Particulate Matter in Urban Households: Sources, Pathways, Characteristics, Health Effects, and Exposure Mitigation. *International Journal of Environmental Research and Public Health*, 18(21), 11055. <https://doi.org/10.3390/ijerph182111055>

⁸² Krieger, J. W., Takaro, T. K., & Rabkin, J. C. (2011). Breathing Easier in Seattle: Addressing Asthma Disparities Through Healthier Housing. In R. A. Williams (Ed.), *Healthcare Disparities at the Crossroads with Healthcare Reform* (pp. 359–383). Springer US. https://doi.org/10.1007/978-1-4419-7136-4_19

⁸³ Pacheco, C. M., Ciaccio, C. E., Nazir, N., Daley, C. M., DiDonna, A., Choi, W. S., Barnes, C. S., & Rosenwasser, L. J. (2014). Homes of low-income minority families with asthmatic children have increased condition issues. *Allergy and Asthma Proceedings*, 35(6), 467–474. <https://doi.org/10.2500/aap.2014.35.3792>

susceptibility to adverse health outcomes when exposed to residential hazards.^{84, 85, 86, 87} Additionally, older adults are disproportionately impacted by indoor environmental quality in part due to increased susceptibility to illness (decreased immune function). Near-elderly populations, defined as older adults, “who are not of retirement age but may lack financial security and resilience,” for example, face more financial hardships than other households; financial hardships are strongly correlated with poorer health and worsening home conditions.⁸⁸ Populations vulnerable to air pollution in Baltimore City, Maryland are discussed in the box below.

POPULATIONS VULNERABLE TO AIR POLLUTION IN BALTIMORE CITY, MD

In Baltimore City, homes in low-income communities are often in deteriorating condition, with environmental hazards present, such as high levels of dust, pests, mold, and poor indoor air quality, among others. Poor indoor air quality can contribute to the development of asthma and can exacerbate symptoms among those with asthma.⁸⁹ Approximately 62 percent of Baltimore City’s population is Black;⁹⁰ Black populations experience a higher rate of poverty, with 23.7 percent of the population living below the federal poverty line compared to 13.5 percent in the U.S. Similarly, Baltimore City has nearly double the rate of households in poverty (20

⁸⁴ Adamkiewicz, G., Zota, A. R., Fabian, M. P., Chahine, T., Julien, R., Spengler, J. D., & Levy, J. I. (2011). Moving Environmental Justice Indoors: Understanding Structural Influences on Residential Exposure Patterns in Low-Income Communities. *American Journal of Public Health*, 101(S1), S238–S245. <https://doi.org/10.2105/AJPH.2011.300119>

⁸⁵ Jacobs, D. E. (2011). Environmental Health Disparities in Housing. *American Journal of Public Health*, 101(S1), S115–S122. <https://doi.org/10.2105/AJPH.2010.300058>

⁸⁶ Mankikar, D., Campbell, C., & Greenberg, R. (2016). Evaluation of a Home-Based Environmental and Educational Intervention to Improve Health in Vulnerable Households: Southeastern Pennsylvania Lead and Healthy Homes Program. *International Journal of Environmental Research and Public Health*, 13(9), 900. <https://doi.org/10.3390/ijerph13090900>

⁸⁷ Tripathii, E., & Laquatra, J. (2018). Managing Indoor Air Quality in the Child Breathing Zone: Risk Analysis and Mitigation. *Journal of Architectural Engineering*, 24(1), 04018002. [https://doi.org/10.1061/\(ASCE\)AE.1943-5568.0000300](https://doi.org/10.1061/(ASCE)AE.1943-5568.0000300)

⁸⁸ Tonn, B., Hawkins, B., Rose, E., & Marincic, M. (2021). Income, housing and health: Poverty in the United States through the prism of residential energy efficiency programs. *Energy Research & Social Science*, 73, 101945. <https://doi.org/10.1016/j.erss.2021.101945>

⁸⁹ Noonan, C. W., & Ward, T. J. (2012). Asthma randomized trial of indoor wood smoke (ARTIS): Rationale and methods. *Contemporary Clinical Trials*, 33(5), 1080–1087. <https://doi.org/10.1016/j.cct.2012.06.006>

⁹⁰ U.S. Census Bureau. (2021). U.S. Census Bureau QuickFacts: United States, Maryland, and Baltimore City. <https://www.census.gov/quickfacts/fact/table/US/PST045221>

percent) compared to the state (10 percent) and the U.S. (12 percent). The poverty rate among Black residents of Baltimore City is 24.1 percent compared to 10.1 percent for White residents.⁹¹

Baltimore City residents also experience a higher rate of child and adult asthma prevalence, asthma-related emergency department visits, hospitalizations, and deaths compared to other Marylanders and the United States as a whole.⁹² For example, 18.6 percent of children living in Baltimore City have asthma compared to the U.S. average of five percent (+/- three percent).⁹³ Black residents in Baltimore City face higher rates of asthma-related emergency room visits (6.5 times more often than White residents), higher asthma hospitalization rates for children (two times the rate of Maryland as a whole), and higher rates of asthma-related mortality (three times higher than White residents).⁹⁴ Baltimore County and other Eastern Shore counties also have higher average annual energy costs and lower median annual household incomes, resulting in higher median annual energy cost burdens as compared to other Maryland counties (**see Chapter 2, Figure 2.2**).

Improvements to indoor air quality in Baltimore would have substantial benefits for residents particularly vulnerable to air pollution exposure, such as children, older adults, those without health insurance, and people of color, who often have limited access to health services and are subjected to worse environmental pollution when compared to White communities.⁹⁵ When comparing Baltimore City's proportion of people of color, people under five years old, and people over age 64 to the state and national average, we find that while the percentage of people under five (all three geographies estimated at six percent) and over 64 (geographies ranged from 14-16 percent) are on par with averages for Maryland and the United States, the percentage of people of color is much greater, estimated to be 73 percent for the City compared to 50 percent for the state and 40 percent for the United States (**Figure 3-1 below**).⁹⁶

⁹¹ [Baltimore, Maryland \(MD\) Poverty Rate Data](#). Accessed 2023.

⁹² GHHL. (2015, April 22). The Green & Healthy Homes Initiative. <https://www.asthmacommunitynetwork.org/node/15680>

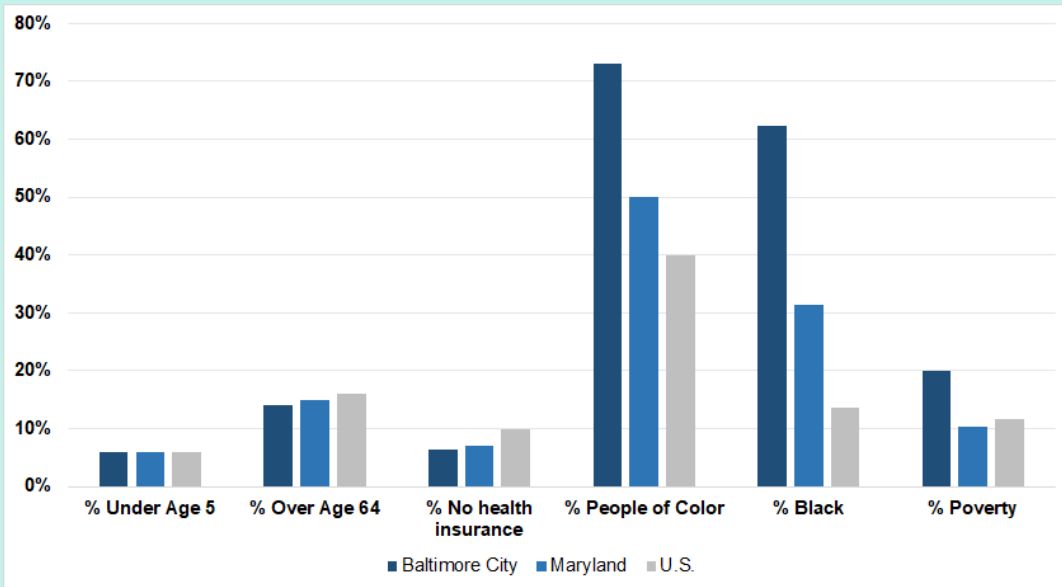
⁹³ Ibid.

⁹⁴ Ibid.

⁹⁵ Ibid.

⁹⁶ U.S. Census Bureau. (2021). U.S. Census Bureau QuickFacts: United States, Maryland, and Baltimore City. <https://www.census.gov/quickfacts/fact/table/US/PST045221>

Figure 3-1: Comparison of socioeconomic indicators in Baltimore City to Maryland and U.S. averages. *Source: 2016-2021 American Community Survey 5-year estimates, U.S. Census (2021).*

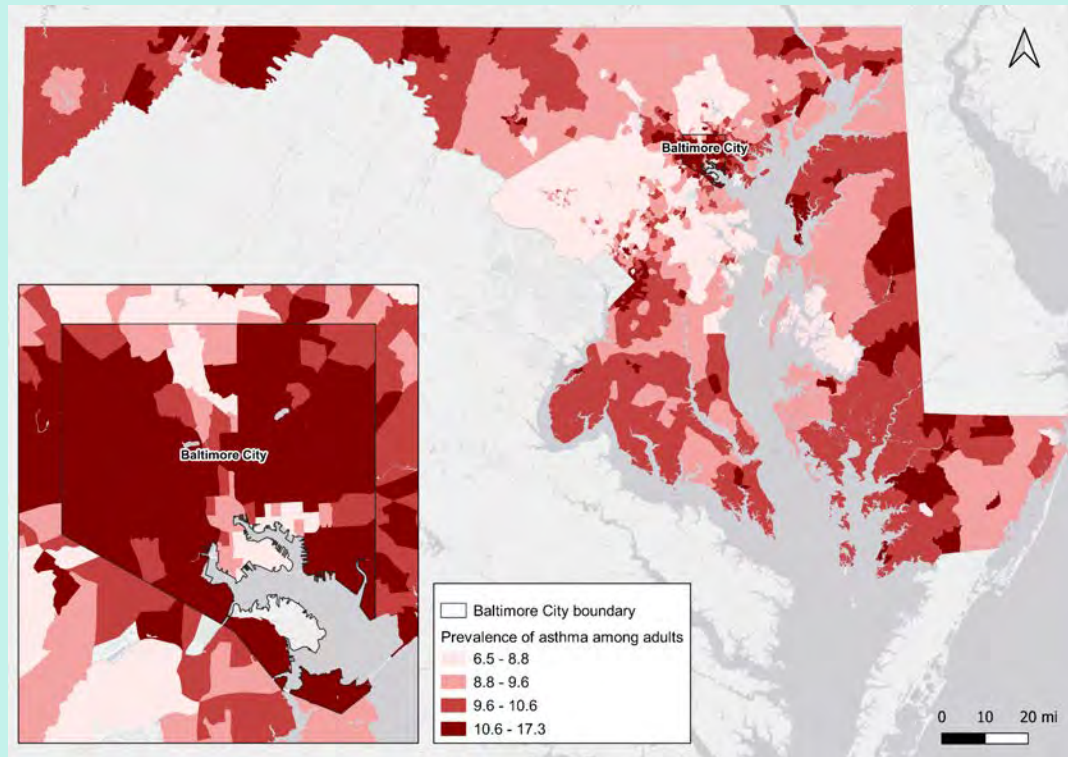


Additionally, the proportion of households without health insurance is lower in Baltimore and the state of Maryland compared to the U.S., with the city and state estimated to be six to seven percent compared to 10 percent nationwide. **Figure 3-2** below shows a map of the percent of asthma prevalence among adults aged 18 years or older.⁹⁷ As you can see in **Figure 3-2**, the majority of Baltimore City neighborhoods have the highest prevalence of asthma compared to averages for the state.⁹⁸

⁹⁷ Asthma prevalence represents the model-based estimate for crude prevalence.

⁹⁸ Centers for Disease Control and Prevention (CDC). (2022.) PLACES Census Tract Data. <https://chronicdata.cdc.gov/500-Cities-Places/PLACES-Census-Tract-Data-GIS-Friendly-Format-2022-/yjkw-uj5s>
<https://data.imap.maryland.gov/datasets/bbe7d09a81fc40c8a7c9f4c80155842e/explore?location=38.810467%2C-77.268400%2C8.94>

Figure 3-2: Model-based estimate for crude prevalence (%) of current asthma among adults aged ≥ 18 years (at the census tract level), 2020, Baltimore City and Maryland. Source: CDC (2022).⁹⁹



3.3 Impacts of Residential Fuel Use on Indoor Air Quality and Health

In this section, we summarize the research on indoor air quality and the health implications of residential energy use. Across Maryland, 43 percent of homes use electricity as their main source of home fuel heating, while the remaining households rely on one or several

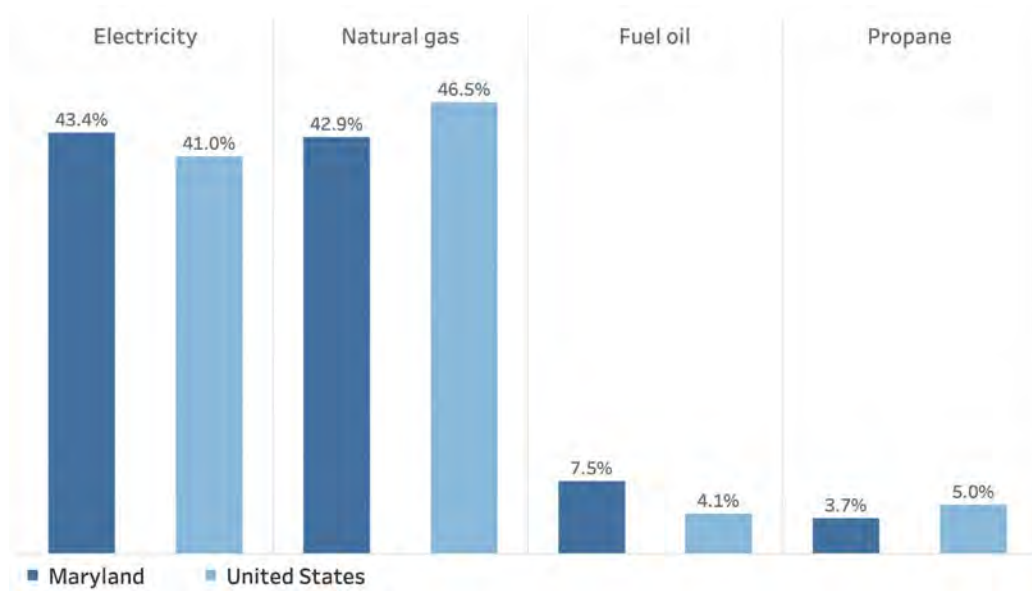
⁹⁹ Klepeis et. al., 2001.

<https://chronicdata.cdc.gov/500-Cities-Places/PLACES-Census-Tract-Data-GIS-Friendly-Format-2022-/vjkw-uj5s>

<https://data.imap.maryland.gov/datasets/bbe7d09a81fc40c8a7c9f4c80155842e/explore?location=38.810467%2C-77.268400%2C8.94>

combustion-based heating fuels that may impact indoor air quality and health (natural gas: 42.9 percent, propane: 3.7 percent, fuel oil: 7.5 percent) (**Figure 3-3**).¹⁰⁰

Figure 3-3: Proportion of main residential heating fuels used in the home, 2021, Maryland statewide average compared to the United States.¹⁰¹



Below, we provide an overview of pollutants associated with combustion appliances (**Section 3.3.1**). We then summarize the impacts of combustion-based cooking (**Section 3.3.2**) and household heating appliances (**Section 3.3.3**), but we note that Marylanders may use additional combustion-based appliances that may influence air quality in their homes (e.g., natural gas dryers).

3.3.1 Key Air Pollutants Associated with Combustion Appliances

While there are various sources of indoor air pollution, in this report, we focus on combustion-based appliances used for cooking and heating. In **Table 3-1** below we summarize key health-relevant pollutants emitted from the combustion and incomplete combustion of natural gas, oil, and biomass and their corresponding health-based standards.

¹⁰⁰ Maryland data from the 2021 American Community Survey, Table S2504 at <https://data.census.gov/table?q=+Maryland+housing&tid=ACST1Y2021.S2504>.

¹⁰¹ Maryland data from the 2021 American Community Survey, Table S2504 at <https://data.census.gov/table?q=+Maryland+housing&tid=ACST1Y2021.S2504>; US data from the Energy Information Administration at <https://www.eia.gov/consumption/residential/data/2020/state/pdf/State%20Space%20Heating%20Fuels.pdf>

Additional health-relevant air pollutants beyond those shown in **Table 3-1** are discussed below with their respective fuel and appliance types.

Table 3-1: Key indoor air pollutants emitted from residential combustion appliances and their associated health-based international, federal, or state standards and relevance for human health. The list of pollutants shown is not inclusive of all relevant pollutants (*Sources: CalEPA OEHHA, 2020; U.S. EPA, 2014, 2016, 2017, 2021; World Health Organization, 2010*).

	Pollutant(s)	Description	Health-Based Standards	Adverse Health Effects
U.S. EPA Criteria Air Pollutants	Fine inhalable particulate matter (PM_{2.5})^a	Liquid- or solid-phase particles suspended in air. Includes soot (i.e., black carbon), organic carbon, and metals	U.S. EPA NAAQS: 12.0 µg/m ³ (1 year) ^b U.S. EPA NAAQS: 35 µg/m ³ (24 hours) ^c	• Premature death in people with pre-existing heart & lung disease • Nonfatal heart attacks • Irregular heartbeat • Low birthweight • Increased respiratory symptoms (coughing, shortness of breath) • Aggravated asthma • Decreased lung function
	Carbon monoxide (CO)	An odorless, colorless gas	WHO: 10 ppm (8 hours) U.S. EPA NAAQS: 9 ppm (8 hours) ^d U.S. EPA NAAQS: 35 ppm (1 hour) ^d	• Fatigue & chest pain, impacts to child mental development (low concentrations) • Impaired vision & coordination, nausea, dizziness, can limit oxygen uptake & be fatal, during pregnancy can cause miscarriages (at high concentrations)
	Nitrogen oxides (NO_x)	A group of highly reactive gases including nitrogen monoxide (NO) and nitrogen dioxide (NO ₂). Combustion of residential fuels emit NO _x primarily in the form of NO but also in the form of NO ₂	NO₂ U.S. EPA NAAQS: 100 ppb (1 hour) ^e U.S. EPA NAAQS: 53 ppb (1 year) WHO: 110 ppb (1 hour) ^f	• Aggravated asthma, resulting in increased respiratory symptoms, emergency department visits, & hospital admissions • NO₂ may contribute to the development of asthma (chronic) • NO_x increases risk of low birth weight, with potential lifelong adverse health implications • NO_x exposure 3 months before pregnancy & first 7 weeks of pregnancy increases risk of

				preterm births, more so for women with asthma
U.S. EPA Hazardous Air Pollutants	Formaldehyde	Colorless, strong-smelling gas	U.S. EPA Inhalation Unit Risk (cancer): 1.3×10^{-5} per $\mu\text{g}/\text{m}^3$ CalEPA OEHHA REL: $55 \mu\text{g}/\text{m}^3$ (1 hour) CalEPA OEHHA REL: $9 \mu\text{g}/\text{m}^3$ (8 hour and chronic)	• Carcinogenic effects • Eye & respiratory irritation (acute) • Adverse non-cancer effects to respiratory system (chronic)
	Benzene	Colorless liquid with a sweet smell that evaporates when exposed to air. Present in distribution-level natural gas as well as being a byproduct of combustion.	U.S. EPA Inhalation Unit Risk (cancer): 2.2×10^{-6} per $\mu\text{g}/\text{m}^3$ CalEPA OEHHA REL: $27 \mu\text{g}/\text{m}^3$ (1 hour) CalEPA OEHHA REL: $3 \mu\text{g}/\text{m}^3$ (8 hour and chronic)	• Carcinogenic effects • Adverse non-cancer effects on development, immune, & hematologic systems (acute) • Adverse non-cancer effects to the hematologic system (chronic)

^a Particulate matter less than or equal to 2.5 microns in diameter.

^b Annual mean, averaged over 3 years.

^c 98th percentile, averaged over 3 years.

^d Not to be exceeded more than once per year.

^e 98th percentile of 1-hour daily maximum concentrations, averaged over 3 years.

^f Annual mean.

(CalEPA OEHHA REL: California Environmental Protection Agency Office of Environmental Health Hazard Assessment Reference Exposure Level; NAAQS: National Ambient Air Quality Standards; ppb: parts per billion; ppm: parts per million; U.S. EPA: United States Environmental Protection Agency; WHO: World Health Organization; $\mu\text{g}/\text{m}^3$: microgram per cubic meter).

Health-based guidance values and standards are commonly established to help mitigate the health impacts associated with harmful environmental hazards by determining a “safe” level of exposure. Health-based guidance values and standards from the U.S. Environmental Protection Agency (U.S. EPA), World Health Organization (WHO), and California Environmental Protection Agency Office of Environmental Health Hazard Assessment (CalEPA OEHHA) are shown for key air pollutants in **Table 3-1**. In most cases, numerical thresholds are set using the best available data, and regulations rely upon established thresholds above which air quality standards would be violated. While some thresholds are designed for outdoor air concentrations (e.g., U.S. EPA National Ambient Air Quality Standards, NAAQS), we consider them for indoor air as no standards for indoor air exist. Indoor air pollution exposure levels

are dependent on the pollutant concentrations in the home and the length of exposure—either short, one-time, or infrequent exposures (acute) or repeated, continuous exposures over a lifetime (chronic).

Key pollutants associated with household combustion appliances include criteria air pollutants and hazardous air pollutants (HAPs). A summary discussion of each pollutant and its associated health impacts is provided below.

Criteria air pollutants. The Clean Air Act requires NAAQS to be set for criteria air pollutants, which encompass six air pollutants known to impact human health and the environment, including ground-level ozone, lead, sulfur dioxide (SO₂), particulate matter (PM), carbon monoxide (CO), and nitrogen oxides (NO_x).¹⁰² Of these pollutants, fine inhalable particulate matter (PM_{2.5}), CO, and NO_x are typically emitted by residential combustion appliances (**Table 3-1**).

Exposure to PM_{2.5} is associated with premature death in people with pre-existing heart and lung disease, as well as nonfatal heart attacks, irregular heartbeat, low birth weight, increased respiratory symptoms (coughing, shortness of breath), aggravated asthma, and decreased lung function. At higher levels, exposure to CO during pregnancy can cause miscarriages; at lower levels, exposure to CO during pregnancy can harm the child’s mental development.¹⁰³ Exposure to CO at low concentrations is associated with fatigue and chest pain, but at high concentrations, exposure can lead to impaired vision and coordination, nausea, dizziness, and can limit oxygen uptake, which can be fatal. Limited oxygen uptake occurs during exposure because CO creates carboxyhemoglobin (COHgb)—a stable complex of carbon monoxide that forms in red blood cells, which inhibits key functions, including delivery of oxygen to cells.¹⁰⁴ The relationship between CO exposure and the prevalence of COHgb in the blood can be determined using the exposure duration and concentration of CO during the exposure event. In some cases, CO exposure to levels as low as 10 ppm can lead to detectable COHb levels of ~2 percent.¹⁰⁵ For context, an elevated COHgb level of 2 percent for non-smokers “strongly supports a diagnosis of CO poisoning.”¹⁰⁶

¹⁰² U.S. EPA. (2014). Criteria Air Pollutants [Other Policies and Guidance].

<https://www.epa.gov/criteria-air-pollutants>

¹⁰³ ATSDR. (2012). Toxicological Profile for Carbon Monoxide (p. 347).

<https://www.atsdr.cdc.gov/ToxProfiles/tp201.pdf>

¹⁰⁴ Ibid.

¹⁰⁵ Rose, J. J., Wang, L., Xu, Q., McTiernan, C. F., Shiva, S., Tejero, J., & Gladwin, M. T. (2017). Carbon Monoxide Poisoning: Pathogenesis, Management, and Future Directions of Therapy. *American Journal of Respiratory and Critical Care Medicine*, 195(5), 596–606. <https://doi.org/10.1164/rccm.201606-1275CI>

¹⁰⁶ CDC. (2020). Clinical Guidance for Carbon Monoxide Poisoning | Natural Disasters and Severe Weather. https://www.cdc.gov/disasters/co_guidance.html

NO_x represents a group of highly reactive gases, including nitrogen monoxide (NO) and nitrogen dioxide (NO₂). Residential combustion emits NO_x primarily in the form of NO but also in the form of NO₂. In the atmosphere, NO is quickly oxidized to NO₂. Similar to CO, NO₂ is also a respiratory irritant that can aggravate pre-existing respiratory diseases like asthma, which may result in increased respiratory symptoms, emergency department visits, and hospital admissions. Long-term exposure to NO₂ may contribute to the development of asthma. NO_x exposure increases the risk of low birth weight, with potential lifelong adverse health implications.¹⁰⁷ Exposure to NO_x in the three months before pregnancy and in the first seven weeks of pregnancy may increase the risk of preterm births, the impacts of which are greater for women with asthma.¹⁰⁸

Hazardous air pollutants. HAPs are pollutants with known or suspected carcinogenic effects or are associated with other serious health impacts, such as reproductive and birth defects.¹⁰⁹ In total, the U.S. EPA has identified 188 pollutants that qualify as HAPs. Key HAPs associated with combustion appliances include, but are not limited to, formaldehyde and benzene (**Table 3-1**). Formaldehyde is a known human carcinogen. Acute exposure can result in eye and respiratory irritation. Long-term exposure is associated with adverse non-cancer effects on the respiratory system.¹¹⁰ Benzene is also a known human carcinogen. Acute exposure can result in adverse non-cancer effects on the development, immune, and hematologic (blood) systems. Long-term exposure is associated with adverse non-cancer effects on the hematologic system.¹¹¹

3.3.2 Cooking Appliances

Combustion appliances used for cooking primarily include ranges, cooktops, and ovens. In Maryland, 40 percent of households have at least one natural gas cooking appliance, similar to national averages, and 69 percent of households have at least one (non-combustion) electric cooking appliance.¹¹² Indoor air quality impacts of cooking appliances can stem from

¹⁰⁷ Mendoza-Ramirez, J., Barraza-Villarreal, A., Hernandez-Cadena, L., de la Garza, O. H., Sangrador, J. L. T., Torres-Sanchez, L. E., Cortez-Lugo, M., Escamilla-Núñez, C., Sanin-Aguirre, L. H., & Romieu, I. (2018). Prenatal Exposure to Nitrogen Oxides and its Association with Birth Weight in a Cohort of Mexican Newborns from Morelos, Mexico. *Annals of Global Health*, 84(2), 274–280. <https://doi.org/10.29024/aogh.914>

¹⁰⁸ Mendola, P., Wallace, M., Hwang, B. S., Liu, D., Robledo, C., Männistö, T., Sundaram, R., Sherman, S., Ying, Q., & Grantz, K. L. (2016). Preterm birth and air pollution: Critical windows of exposure for women with asthma. *Journal of Allergy and Clinical Immunology*, 138(2), 432–440.e5. <https://doi.org/10.1016/j.jaci.2015.12.1309>

¹⁰⁹ U.S. EPA. (2015). Hazardous Air Pollutants [Collections and Lists]. <https://www.epa.gov/haps>

¹¹⁰ ATSDR. (1999). Toxicological Profile for Formaldehyde. <https://www.atsdr.cdc.gov/toxprofiles/tp111.pdf>

¹¹¹ ATSDR. (2007). Toxicological Profile for Benzene. <https://www.atsdr.cdc.gov/toxprofiles/tp3.pdf>

¹¹² U.S. EIA (Energy Information Administration). (2022). Highlights for appliances in U.S. homes by state, 2020. <https://www.eia.gov/consumption/residential/data/2020/state/pdf/State%20Appliances.pdf>

gas appliance leaks,^{113, 114} from combustion or incomplete combustion of gas during cooking,^{115, 116} and from food that is being cooked.¹¹⁷ Gas stoves, cooktops, and ovens can leak when not in use, resulting in indoor emissions of methane, the primary component of natural gas and a potent greenhouse gas, along with hazardous air pollutants such as benzene, hexane, and toluene, among others.^{118, 119, 120} Of note, gas composition can vary by region^{121, 122} and seasonally.¹²³ Combustion of natural gas during cooking results in direct emissions of criteria air pollutants, including NO_x.¹²⁴ The blending of natural gas with hydrogen may hold implications for enhanced NO_x emissions. There are mixed results for changes in NO_x emissions associated with residential end-use combustion reported in the peer-reviewed

¹¹³ Lebel, E. D., Finnegan, C. J., Ouyang, Z., & Jackson, R. B. (2022). Methane and NO_x Emissions from Natural Gas Stoves, Cooktops, and Ovens in Residential Homes. *Environmental Science & Technology*, 56(4), 2529–2539. <https://doi.org/10.1021/acs.est.1c04707>

¹¹⁴ Michanowicz, D. R., Dayalu, A., Nordgaard, C. L., Buonocore, J. J., Fairchild, M. W., Ackley, R., Schiff, J. E., Liu, A., Phillips, N. G., Schulman, A., Magavi, Z., & Spengler, J. D. (2022). Home is Where the Pipeline Ends: Characterization of Volatile Organic Compounds Present in Natural Gas at the Point of the Residential End User. *Environmental Science & Technology*, acs.est.1c08298. <https://doi.org/10.1021/acs.est.1c08298>

¹¹⁵ Lebel, E. D., Finnegan, C. J., Ouyang, Z., & Jackson, R. B. (2022). Methane and NO_x Emissions from Natural Gas Stoves, Cooktops, and Ovens in Residential Homes. *Environmental Science & Technology*, 56(4), 2529–2539. <https://doi.org/10.1021/acs.est.1c04707>

¹¹⁶ Mullen, N. A., Li, J., Russell, M. L., Spears, M., Less, B. D., & Singer, B. C. (2016). Results of the California Healthy Homes Indoor Air Quality Study of 2011–2013: Impact of natural gas appliances on air pollutant concentrations. *Indoor Air*, 26(2), 231–245. <https://doi.org/10.1111/ina.12190>

¹¹⁷ Zhai, S. R., & Albritton, D. (2020). Airborne particles from cooking oils: Emission test and analysis on chemical and health implications. *Sustainable Cities and Society*, 52, 101845. <https://doi.org/10.1016/j.scs.2019.101845>

¹¹⁸ Lebel, E. D., Finnegan, C. J., Ouyang, Z., & Jackson, R. B. (2022). Methane and NO_x Emissions from Natural Gas Stoves, Cooktops, and Ovens in Residential Homes. *Environmental Science & Technology*, 56(4), 2529–2539. <https://doi.org/10.1021/acs.est.1c04707>

¹¹⁹ Lebel, E. D., Michanowicz, D. R., Bilsback, K. R., Hill, L. L., Goldman, J. S. W., Domen, J. K., Jaeger, J. M., Ruiz, A., & Shonkoff, S. B. C. (2022). Composition, Emissions, and Air Quality Impacts of Hazardous Air Pollutants in Unburned Natural Gas from Residential Stoves in California. *Environmental Science & Technology*. <https://doi.org/10.1021/acs.est.2c02581>

¹²⁰ Michanowicz, D. R., Dayalu, A., Nordgaard, C. L., Buonocore, J. J., Fairchild, M. W., Ackley, R., Schiff, J. E., Liu, A., Phillips, N. G., Schulman, A., Magavi, Z., & Spengler, J. D. (2022). Home is Where the Pipeline Ends: Characterization of Volatile Organic Compounds Present in Natural Gas at the Point of the Residential End User. *Environmental Science & Technology*, acs.est.1c08298. <https://doi.org/10.1021/acs.est.1c08298>

¹²¹ Lebel, E. D., Michanowicz, D. R., Bilsback, K. R., Hill, L. L., Goldman, J. S. W., Domen, J. K., Jaeger, J. M., Ruiz, A., & Shonkoff, S. B. C. (2022). Composition, Emissions, and Air Quality Impacts of Hazardous Air Pollutants in Unburned Natural Gas from Residential Stoves in California. *Environmental Science & Technology*. <https://doi.org/10.1021/acs.est.2c02581>

¹²² Michanowicz, D. R., Dayalu, A., Nordgaard, C. L., Buonocore, J. J., Fairchild, M. W., Ackley, R., Schiff, J. E., Liu, A., Phillips, N. G., Schulman, A., Magavi, Z., & Spengler, J. D. (2022). Home is Where the Pipeline Ends: Characterization of Volatile Organic Compounds Present in Natural Gas at the Point of the Residential End User. *Environmental Science & Technology*, acs.est.1c08298. <https://doi.org/10.1021/acs.est.1c08298>

¹²³ Ibid.

¹²⁴ Lebel, E. D., Finnegan, C. J., Ouyang, Z., & Jackson, R. B. (2022). Methane and NO_x Emissions from Natural Gas Stoves, Cooktops, and Ovens in Residential Homes. *Environmental Science & Technology*, 56(4), 2529–2539. <https://doi.org/10.1021/acs.est.1c04707>

literature, with mean and worst case NO_x emission scenarios indicating increases in NO_x emissions with hydrogen blending.¹²⁵

Ventilation by whole-house mechanical ventilation, the use of range hoods (particularly those that vent externally rather than recirculate air), and the opening of windows can reduce indoor air pollution during cooking (see **Section 3.4.2**). Studies evaluating the influences of gas versus electric stoves on indoor air quality show that combustion-related air pollutant concentrations were significantly reduced in homes with electric appliances (see **Section 3.4.3**).^{126, 127} Given our focus in this section on combustion-based cooking appliances, below we discuss studies that report elevated indoor air pollutant concentrations associated with natural gas cooking appliances, including studies that report exceedances of health-based standards.

3.3.2.1 Indoor Air Pollutant Concentrations Associated With Natural Gas Cooking Appliances

The majority of studies that compare indoor air concentrations to health-based guidance values and standards are focused on gas stoves, ranges, and burners as significant indoor sources of air pollution. Studies described below were focused in California. A study measuring indoor air quality in low-income apartments with natural gas cooking appliances found that measured indoor PM_{2.5} and NO₂ concentrations exceeded the U.S. EPA NAAQS and California Ambient Air Quality Standards (CAAQS) for ambient air quality and World Health Organization's limits for personal exposure. Concentrations of formaldehyde, for which there are numerous indoor sources, including but not limited to gas stoves, were generally above CalEPA chronic reference exposure levels.¹²⁸ In a study focused on natural gas cooking burner usage in households in Northern California, researchers at Lawrence Berkeley National Laboratory observed that indoor NO₂ concentrations in nearly half of homes exceeded the 1-hour NAAQS (100 parts per billion [ppb] NO₂) during operation of the burners with venting range hoods; although, range hood use substantially reduced indoor cooking pollutant

¹²⁵ Wright, M. L., & Lewis, A. C. (2022). Emissions of NO_x from blending of hydrogen and natural gas in space heating boilers. *Elementa: Science of the Anthropocene*, 10(1), 00114. <https://doi.org/10.1525/elementa.2021.00114>

¹²⁶ Mullen, N. A., Li, J., Russell, M. L., Spears, M., Less, B. D., & Singer, B. C. (2016b). Results of the California Healthy Homes Indoor Air Quality Study of 2011–2013: Impact of natural gas appliances on air pollutant concentrations. *Indoor Air*, 26(2), 231–245. <https://doi.org/10.1111/ina.12190>

¹²⁷ Paulin, L. M., Diette, G. B., Scott, M., McCormack, M. C., Matsui, E. C., Curtin-Brosnan, J., Williams, D. L., Kidd-Taylor, A., Shea, M., Breyse, P. N., & Hansel, N. N. (2014). Home interventions are effective at decreasing indoor nitrogen dioxide concentrations. *Indoor Air*, 24(4), 416–424. <https://doi.org/10.1111/ina.12085>

¹²⁸ Zhao, H., Chan, W. R., Cohn, S., Delp, W. W., Walker, I. S., & Singer, B. C. (2021). Indoor air quality in new and renovated low-income apartments with mechanical ventilation and natural gas cooking in California. *Indoor Air*, 31(3), 717–729. <https://doi.org/10.1111/ina.12764>

concentrations.¹²⁹ Modeled estimates of natural gas cooking burner emissions in California homes without ventilation also suggested that occupants may be exposed to NO₂, CO, and formaldehyde concentrations during cooking that exceeds the acute national and state health-based standards.¹³⁰ Further, the use of ventilation hoods are not ubiquitous in houses or apartments that have hoods.¹³¹ A recent study measuring air pollutant concentrations in homes with gas stoves found that indoor concentrations of NO_x were correlated with the amount of natural gas burned during stove usage. Additionally, the authors found that the 1-hr NAAQS for NO₂ (100 ppb) can be exceeded within a few minutes of stove usage, particularly in small kitchens with poor ventilation.¹³² Another recent study measured HAP concentrations in natural gas from gas stoves across California, using measured leakage rates when stoves were not in use to estimate indoor concentrations of benzene. The authors found that leakage from stoves and ovens not in use can result in benzene concentrations that exceed the California EPA 8-hour and chronic reference exposure level and in some cases are comparable to tobacco smoke.¹³³

3.3.2.2 Maryland Department of Housing and Community Development Compliance Appliance Safety Inspections

The Maryland Department of Housing and Community Development (DHCD) performed combustion appliance safety inspections for vented appliances in households by measuring indoor CO concentrations near combustion appliances. Combustion appliances are a significant source of CO indoors. CO is an odorless, colorless, toxic gas. Exposure to CO can be fatal at high concentrations over short durations and is associated with various adverse health effects at lower levels.¹³⁴ CO is also a criteria air pollutant, for which the U.S. EPA establishes

¹²⁹ Singer, B. C., Pass, R. Z., Delp, W. W., Lorenzetti, D. M., & Maddalena, R. L. (2017). Pollutant concentrations and emission rates from natural gas cooking burners without and with range hood exhaust in nine California homes. *Building and Environment*, 122, 215–229. <https://doi.org/10.1016/j.buildenv.2017.06.021>

¹³⁰ Logue, J. M., Klepeis, N. E., Lobscheid, A. B., & Singer, B. C. (2014). Pollutant Exposures from Natural Gas Cooking Burners: A Simulation-Based Assessment for Southern California. *Environmental Health Perspectives*, 122(1), 43–50. <https://doi.org/10.1289/ehp.1306673>

¹³¹ Zhao, H., Chan, W. R., Delp, W. W., Tang, H., Walker, I. S., & Singer, B. C. (2020). Factors Impacting Range Hood Use in California Houses and Low-Income Apartments. *International Journal of Environmental Research and Public Health*, 17(23), 8870. <https://doi.org/10.3390/ijerph17238870>

¹³² Lebel, E. D., Finnegan, C. J., Ouyang, Z., & Jackson, R. B. (2022). Methane and NO_x Emissions from Natural Gas Stoves, Cooktops, and Ovens in Residential Homes. *Environmental Science & Technology*, 56(4), 2529–2539. <https://doi.org/10.1021/acs.est.1c04707>

¹³³ Lebel, E. D., Michanowicz, D. R., Bilsback, K. R., Hill, L. L., Goldman, J. S. W., Domen, J. K., Jaeger, J. M., Ruiz, A., & Shonkoff, S. B. C. (2022). Composition, Emissions, and Air Quality Impacts of Hazardous Air Pollutants in Unburned Natural Gas from Residential Stoves in California. *Environmental Science & Technology*. <https://doi.org/10.1021/acs.est.2c02581>

¹³⁴ U.S. EPA. (2021). Carbon Monoxide's Impact on Indoor Air Quality [Overviews and Factsheets]. <https://www.epa.gov/indoor-air-quality-iaq/carbon-monoxides-impact-indoor-air-quality>

NAAQS for outdoor air to protect public health and welfare (**Table 3-1**).¹³⁵ Indoor ambient CO concentrations were measured in “*combustion appliance zones*”, namely in close proximity to residential combustion appliances, including cooking appliances such as cook stoves and gas ovens.¹³⁶ Throughout the inspections, 4,626 combustion appliances were evaluated across 2,257 Maryland residences in 2021. Residences included single family homes, multifamily apartment units, mobile homes, and renter- and owner-occupied spaces.^{137,138}

Table 3-2 summarizes measured indoor CO concentrations by combustion appliance type. Briefly, 98 (2.1 percent) of the combustion *appliances* evaluated had indoor CO concentrations detected at or above ($\geq$) nine parts per million (ppm) within the respective combustion appliance zone after approximately five to 10 minutes with the main burner in operation.¹³⁹ Nine ppm is the NAAQS for CO concentrations averaged over an eight-hour period and is not to be exceeded more than once per year (U.S. EPA, 2022; **Table 3-1**). However, concentrations below reflect single point in time measurements and are not necessarily reflective of indoor air concentrations over longer durations.

As part of the compliance safety inspections, if concentrations greater than or equal to nine ppm are detected, it is recommended that 1) the occupant be notified that CO has been detected, 2) the area be ventilated, and 3) the occupant contacts a qualified professional to evaluate potential appliance sources of CO (BPI, 2016). Seventy-eight (3.5 percent) of *households* evaluated had at least one combustion appliance with indoor CO detected $\geq$ nine ppm; twenty households (0.89 percent) had more than one combustion appliance with indoor CO detected greater than or equal to nine ppm within the combustion appliance zones. Notably, over five percent of cook stoves and gas ovens evaluated had indoor CO detected $\geq$ nine ppm (**Table 3-2**).

¹³⁵ U.S. EPA. (2022). NAAQS Table [Other Policies and Guidance].

<https://www.epa.gov/criteria-air-pollutants/naaqs-table>

¹³⁶ Building Performance Institute, Inc. (BPI). (2016). Combustion Appliance Safety Inspection for Vented Appliances.

<https://www.bpi.org/sites/default/files/COMBUSTION%20APPLIANCE%20SAFETY%20INSPECTION%20FOR%20VENTED%20APPLIANCES.pdf>

¹³⁷ Maryland Department of Housing and Community Development (DHCD). (2022).

¹³⁸ While the Maryland Department of Housing and Community Development sample is large, consisting of more than two thousand housing units, it is not necessarily a statistically representative sample of the population in Maryland since the sample consists entirely of low-income households receiving weatherization assistance. There are about 1.2 million gas customers in Maryland (see **Chapter 4, Table 4-2**). There are therefore millions of non-electric combustion appliances in the state, including space and water heating as well as gas stoves and ovens.

¹³⁹ While main burners in cooking appliances (gas stoves and ovens) were in operation at the time of measurement, cooking activities (e.g., sauteing or baking of foods or boiling of water) did not occur during sampling.

Sixty combustion appliances (1.3 percent) evaluated had indoor ambient CO measured ≥ 35 ppm. 35 ppm is the NAAQS for CO averaged over a one-hour period and is not to be exceeded more than once per year (U.S. EPA, 2022). If concentrations above 35 ppm are detected, in addition to the recommendations mentioned above, it is also recommended that potential sources of CO are turned off (BPI, 2016). Forty-three households (1.9 percent) had at least one combustion appliance with indoor ambient CO concentration detected ≥ 35 ppm within the combustion appliance zone. Sixteen households (0.71 percent) had more than one combustion appliance with indoor ambient CO concentrations detected ≥ 35 ppm within the combustion appliance zone. Of combustion appliance types, cook stoves were most likely to have measured indoor CO concentrations ≥ 35 ppm within the combustion appliances zone (3.7 percent) (**Table 3-2**).

For indoor CO concentrations over 70 ppm, occupant evacuation is recommended and emergency services should be notified. There were 40 instances of ambient air in rooms with appliances with concentrations higher than 70 ppm; 20 of these were in kitchens (19 associated with a gas stove and one with an oven).

Cook stoves were also associated with the highest observed indoor CO concentration within a combustion appliance zone (91.9 ppm), with a maximum concentration of more than 2.5 times the 1-hour NAAQS for ambient CO (**Table 3-2**). More than five percent of gas stoves and ovens exhibited concentrations of more than 9 ppm and more than three percent of kitchens with gas stoves had over 35 ppm levels of CO.

Table 3-2: Indoor CO concentrations observed in the ambient air in the room with the combustion appliance at five minutes of main burner operation, by appliance type. Counts reflect the number of appliances by appliance type with indoor CO concentration exceeding the specified threshold. Percent (%) reflects the proportion of appliances by appliance type evaluated with indoor CO concentrations that exceeded specified thresholds. (Raw data source: DHCD, 2022)

Appliance Type	≥ 9 ppm (%)	≥ 35 ppm (%)	≥ 70 ppm (%)	Maximum Observed Value (ppm)
Cook stove ¹	39 (5.4%)	27 (3.7%)	19 (2.6%)	91.9
Furnace	26 (1.8%)	23 (1.6%)	14 (1.0%)	90.1
Gas oven	23 (5.6%)	1 (0.2%)	1 (0.2%)	80.6
Hot water tank	9 (0.7%)	8 (0.6%)	6 (5.4%)	87.9
Gas fireplace	1 (4.5%)	0 (0.0%)	0 (0.0%)	18
Total	98 (2.1%)	59 (1.3%)	40 (0.9%)	-

¹ Consolidated counts of “Cook Stove”, “Cook Stove2”, “Cooktop Frnt Rt”, “Cooktop Rear Lft”, and “Cooktop Rear Rt” from original dataset.

² Fuel type for specific appliances was not able to be determined based on available data. Natural gas is assumed to be the primary fuel type for cooking appliances, whereas heating appliances may rely on natural gas, propane, oil, etc.

3.3.2.3 Health Risks and Impacts Associated with Gas Cooking Appliances

While many studies examine indoor air pollutant concentrations and emissions, few studies explicitly evaluate specific health risks and impacts associated with gas cooking appliances. One study focused in Baltimore evaluated the effect of indoor NO₂ concentrations on asthma morbidity among inner-city preschool children, and found that higher household indoor NO₂ concentrations were associated with increased asthma symptoms. Furthermore, the presence of a gas stove and the use of a space heater or oven/stove for heat were associated with higher NO₂ concentrations.¹⁴⁰ A recent study estimated the population level effects of gas stove use

¹⁴⁰ Hansel, N. N., Breyse, P. N., McCormack, M. C., Matsui, E. C., Curtin-Brosnan, J., Williams, D. L., Moore, J. L., Cuhnan, J. L., & Diette, G. B. (2008). A longitudinal study of indoor nitrogen dioxide levels and respiratory symptoms in inner-city children with asthma. *Environmental Health Perspectives*, 116(10), 1428–1432. <https://doi.org/10.1289/ehp.11349>

on current childhood asthma in the U.S.¹⁴¹ The authors found that 12.7 percent of current childhood asthma cases in the U.S. can be attributed to gas stove use.

Additional studies suggest the use of ventilation in homes with gas stoves as a protective factor. A study focused across the United States found that in homes with gas stoves, children of parents who reported using ventilation when using the stove had lower odds of asthma, wheeze, and bronchitis and higher lung function compared to homes that did not use ventilation or did not have access to ventilation options.¹⁴²

3.3.3 Heating Appliances

Residential heating appliances that rely on combustion (e.g., gas fireplaces, gas furnaces, or wood stoves) may contribute to indoor air pollution, especially if they are vented indoors. Residential space heating in Maryland is dominated by natural gas and electricity (each about 43 percent), 7.5 percent fuel oil or kerosene and 3.7 percent propane, with the rest being other fuels or no fuel (**Figure 3-3 above**). For geographic distribution of fuel use for heating in Maryland, see **Chapter 2, Figure 2.7**. Below, we summarize the literature on the indoor air quality and health impacts of heating by fuel and appliance type.

3.3.3.1 Indoor Air Pollutant Concentrations Associated with Heating Appliances

3.3.3.1.1 Gas Heating Appliances

Measurements from the literature indicate that gas heating leads to elevated levels of air pollutants indoors.^{143, 144, 145, 146} For example, a study measuring CO, NO₂, and polycyclic

¹⁴¹ Gruenwald, T., Seals, B. A., Knibbs, L. D., & Hosgood, H. D. (2023). Population Attributable Fraction of Gas Stoves and Childhood Asthma in the United States. *International Journal of Environmental Research and Public Health*, 20(1), Article 1. <https://doi.org/10.3390/ijerph20010075>

¹⁴² Kile, M. L., Coker, E. S., Smit, E., Sudakin, D., Molitor, J., & Harding, A. K. (2014). A cross-sectional study of the association between ventilation of gas stoves and chronic respiratory illness in U.S. children enrolled in NHANESIII. *Environmental Health*, 13(1), 71. <https://doi.org/10.1186/1476-069X-13-71>

¹⁴³ Dutton, S. J., Hannigan, M. P., & Miller, S. L. (2001). Indoor Pollutant Levels from the Use of Unvented Natural Gas Fireplaces in Boulder, Colorado. *Journal of the Air & Waste Management Association*, 51(12), 1654–1661. <https://doi.org/10.1080/10473289.2001.10464395>

¹⁴⁴ Francisco, P. W., Gordon, J. R., & Rose, B. (2010). Measured concentrations of combustion gases from the use of unvented gas fireplaces: Field measurements of unvented gas fireplaces. *Indoor Air*, 20(5), 370–379. <https://doi.org/10.1111/j.1600-0668.2010.00659.x>

¹⁴⁵ Mullen, N. A., Li, J., Russell, M. L., Spears, M., Less, B. D., & Singer, B. C. (2016). Results of the California Healthy Homes Indoor Air Quality Study of 2011–2013: Impact of natural gas appliances on air pollutant concentrations. *Indoor Air*, 26(2), 231–245. <https://doi.org/10.1111/ina.12190>

¹⁴⁶ Casey, J. G., Ortega, J., Coffey, E., & Hannigan, M. (2018). Low-cost measurement techniques to characterize the influence of home heating fuel on carbon monoxide in Navajo homes. *Science of The Total Environment*, 625, 608–618. <https://doi.org/10.1016/j.scitotenv.2017.12.312>

aromatic hydrocarbons (PAHs) in two homes (Boulder, CO) found that the use of an unvented gas fireplace increased levels of all three pollutants.¹⁴⁷ In another study, researchers measured CO concentrations in 17 homes that were heated with gas (i.e., natural gas or propane) and found elevated peak concentrations of CO.¹⁴⁸ Further, a study measured elevated levels of NO_x (and NO₂) in homes that had pilot burners in their gas furnaces compared to homes that did not have pilot burners, but noted that the differences became less apparent when adjusted for home size.¹⁴⁹

Heating with unvented gas fireplaces, which do not have a chimney and therefore release combustion products directly into the living space, may be of particular concern. In a study that measured concentrations of combustion byproducts in 30 homes where unvented gas fireplaces were used, researchers found that in 43 percent of the homes studied, NO₂ levels exceeded the 1-hour WHO threshold (110 ppb) and in 20 percent of the homes studied, CO levels exceeded the 8-hour U.S. EPA NAAQS guideline (9 ppm).¹⁵⁰ In contrast, a study funded by the Propane Education & Research Council, an organization that is funded and operated by the propane industry,¹⁵¹ used an indoor air quality model to conclude that unvented gas fireplaces would not exceed health-based standards for CO and NO₂, noting that previous studies did not consider unvented fireplaces that met current certification requirements. We note that these modeled results should elicit some skepticism as they are counter to measured exceedances.¹⁵² Moreover, there are unvented gas fireplaces of various vintages in use; therefore even older publications (2010) should give regulators and health authorities pause in regard to the continued use and sale of these appliances.

¹⁴⁷ Dutton, S. J., Hannigan, M. P., & Miller, S. L. (2001). Indoor Pollutant Levels from the Use of Unvented Natural Gas Fireplaces in Boulder, Colorado. *Journal of the Air & Waste Management Association*, 51(12), 1654–1661. <https://doi.org/10.1080/10473289.2001.10464395>

¹⁴⁸ Casey, J. G., Ortega, J., Coffey, E., & Hannigan, M. (2018). Low-cost measurement techniques to characterize the influence of home heating fuel on carbon monoxide in Navajo homes. *Science of The Total Environment*, 625, 608–618. <https://doi.org/10.1016/j.scitotenv.2017.12.312>

¹⁴⁹ Mullen, N. A., Li, J., Russell, M. L., Spears, M., Less, B. D., & Singer, B. C. (2016). Results of the California Healthy Homes Indoor Air Quality Study of 2011–2013: Impact of natural gas appliances on air pollutant concentrations. *Indoor Air*, 26(2), 231–245. <https://doi.org/10.1111/ina.12190>

¹⁵⁰ Francisco, P. W., Gordon, J. R., & Rose, B. (2010). Measured concentrations of combustion gases from the use of unvented gas fireplaces: Field measurements of unvented gas fireplaces. *Indoor Air*, 20(5), 370–379. <https://doi.org/10.1111/j.1600-0668.2010.00659.x>

¹⁵¹ Whitmyre, G. K., & Pandian, M. D. (2018). Probabilistic assessment of the potential indoor air impacts of vent-free gas heating appliances in energy-efficient homes in the United States. *Journal of the Air & Waste Management Association*, 68(6), 616–625. <https://doi.org/10.1080/10962247.2018.1426652>

¹⁵² Francisco, P. W., Gordon, J. R., & Rose, B. (2010). Measured concentrations of combustion gases from the use of unvented gas fireplaces: Field measurements of unvented gas fireplaces. *Indoor Air*, 20(5), 370–379. <https://doi.org/10.1111/j.1600-0668.2010.00659.x>

3.3.3.1.2 Wood Heating Appliances

The evidence reviewed here strongly indicates that wood-based heating can lead to exceedances of health-based air quality standards. For example, researchers measured indoor PM_{2.5} concentrations over 6 days in homes that used wood stoves in the rural United States and found that 70 percent of homes had PM_{2.5} concentrations that exceeded the U.S. EPA's annual NAAQS for PM_{2.5} (12 µg m⁻³; **Table 3-1**).¹⁵³ Additionally, two studies both measured 48-hour PM_{2.5} concentrations in homes using wood stoves and observed that the study-average PM_{2.5} concentrations were similar to the U.S. EPA's 24-hour NAAQS for PM_{2.5} (35 µg m⁻³; **Table 3-1**).^{154,155} Further, researchers found exceedances of the 8-hour (10 ppm) WHO guidelines for indoor air quality in some wood-burning homes.¹⁵⁶

Under some conditions wood pellet stoves may have lower emissions than wood stoves that burn logs,^{157, 158} however, wood pellet storage systems may also lead to degraded indoor air quality. Wood pellet boilers may require several tons of wood pellets per year and are often stored in rooms or large bag-type containers. Off-gassing from these large pellet quantities in enclosed storage locations may lead to CO concentrations that exceed health-based guidelines and have reportedly led to fatal accidents.¹⁵⁹ Scientists recommend that storage areas be equipped with a CO monitor and alarm system and that rebate programs for the installation of wood-pellet boilers include clauses that require outdoor bulk pellet storage.¹⁶⁰

Interventions aimed at reducing indoor air pollutant concentrations and subsequent exposures from wood-fueled appliances led to mixed results, highlighting that meaningful

¹⁵³ Walker, I., Less, B., Lorenzetti, D., & Sohn, M. D. (2021). Development of Advanced Smart Ventilation Controls for Residential Applications. *Energies*, 14(17), 5257. <https://doi.org/10.3390/en14175257>

¹⁵⁴ McNamara, M., Thornburg, J., Semmens, E., Ward, T., & Noonan, C. (2013). Coarse particulate matter and airborne endotoxin within wood stove homes. *Indoor Air*, 23(6), 498–505. <https://doi.org/10.1111/ina.12043>

¹⁵⁵ Semmens, E. O., Noonan, C. W., Allen, R. W., Weiler, E. C., & Ward, T. J. (2015). Indoor particulate matter in rural, wood stove heated homes. *Environmental Research*, 138, 93–100. <https://doi.org/10.1016/j.envres.2015.02.005>

¹⁵⁶ Casey, J. G., Ortega, J., Coffey, E., & Hannigan, M. (2018). Low-cost measurement techniques to characterize the influence of home heating fuel on carbon monoxide in Navajo homes. *Science of The Total Environment*, 625, 608–618. <https://doi.org/10.1016/j.scitotenv.2017.12.312>

¹⁵⁷ Båfver, L. S., Leckner, B., Tullin, C., & Berntsen, M. (2011). Particle emissions from pellets stoves and modern and old-type wood stoves. *Biomass and Bioenergy*, 35(8), 3648–3655. <https://doi.org/10.1016/j.biombioe.2011.05.027>

¹⁵⁸ Lamberg, H., Sippula, O., Tissari, J., Virén, A., Kaivosoja, T., Aarinen, A., Salminen, V., & Jokiniemi, J. (2017). Operation and Emissions of a Hybrid Stove Fueled by Pellets and Log Wood. *Energy & Fuels*, 31(2), 1961–1968. <https://doi.org/10.1021/acs.energyfuels.6b02717>

¹⁵⁹ Soto-Garcia, L., Huang, X., Thimmaiah, D., Rossner, A., & Hopke, P. K. (2015). Exposures to Carbon Monoxide from Off-Gassing of Bulk Stored Wood Pellets. *Energy & Fuels*, 29(1), 218–226. <https://doi.org/10.1021/ef5021186>

¹⁶⁰ Rossner, A., Jordan, C. E., Wake, C., & Soto-Garcia, L. (2017). Monitoring of carbon monoxide in residences with bulk wood pellet storage in the Northeast United States. *Journal of the Air & Waste Management Association*, 67(10), 1066–1079. <https://doi.org/10.1080/10962247.2017.1321054>

improvements may require a multi-source intervention approach. For example, researchers conducted a community-scale intervention in Libby, Montana replacing old wood-burning stove models with new EPA-certified wood stoves and they found that the stove interventions reduced indoor PM_{2.5} by 54 percent on average, but that a subset of homes did not experience PM_{2.5} reductions.¹⁶¹ While another study conducted in Alaska, Montana, and the Navajo Nation (Arizona and New Mexico) did not find meaningful differences in PM_{2.5} (or health effects) through low-cost education and air filtration interventions.¹⁶²

3.3.3.2 DHCD Data on Heating Appliances

In the Maryland Department of Housing and Community Development combustion appliance inspections (described above), indoor CO measurements were collected in the rooms with household and water heating appliances, including furnaces, hot water heaters, and gas fireplaces. 1.6 percent of furnaces and 0.6 percent of hot water tanks had measured indoor CO concentrations $\geq$ 35 ppm in rooms with combustion appliances (**Table 3-2**). Among heating appliances, furnaces and hot water tanks had high observed indoor ambient CO concentration measured within the combustion appliance zone (90.1 ppm and 87.9 ppm, respectively) (**Table 3-2**). These maximum concentrations are more than 2.5 times the 1-hour NAAQS for ambient CO and represent levels at which evacuation is recommended.

3.3.3.3 Health Risks and Impacts Associated with Heating Appliances

3.3.3.3.1 Gas Heating Appliances

One study found that using gas stoves for heat without ventilation increased the risk of pneumonia and cough, compared to children who lived in homes where gas was only used for cooking.¹⁶³ This study was extensive, using >3,000 parent-reported data points for multiple respiratory symptoms of children under 5 years old from the National Health and Nutrition Examination Survey (1988–1994).

¹⁶¹ Noonan, C. W., & Ward, T. J. (2012). Asthma randomized trial of indoor wood smoke (ARTIS): Rationale and methods. *Contemporary Clinical Trials*, 33(5), 1080–1087. <https://doi.org/10.1016/j.cct.2012.06.006>

¹⁶² Walker, E. S., Semmens, E. O., Belcourt, A., Boyer, B. B., Erdei, E., Graham, J., Hopkins, S. E., Lewis, J. L., Smith, P. G., Ware, D., Weiler, E., Ward, T. J., & Noonan, C. W. (2022). Efficacy of Air Filtration and Education Interventions on Indoor Fine Particulate Matter and Child Lower Respiratory Tract Infections among Rural U.S. Homes Heated with Wood Stoves: Results from the KidsAIR Randomized Trial. *Environmental Health Perspectives*, 130(4), 047002. <https://doi.org/10.1289/EHP9932>

¹⁶³ Coker, E. S., Smit, E., Harding, A. K., Molitor, J., & Kile, M. L. (2015). A cross sectional analysis of behaviors related to operating gas stoves and pneumonia in U.S. children under the age of 5. *BMC Public Health*, 15(1), 77. <https://doi.org/10.1186/s12889-015-1425-y>

3.3.3.3.2 Wood Heating Appliances

Several studies have found health outcomes associated with the use of wood for heating. In a study of Alaska Native children’s respiratory symptoms, researchers reported that the use of wood fuel as a primary heat source was associated with a higher risk of coughs between colds.¹⁶⁴ Furthermore, a New York-based study found that burning synthetic logs in a fireplace increased breast cancer risk by 42 percent, although there was not a significant increase in risk from burning wood alone.¹⁶⁵

Studies that investigated the efficacy of interventions in reducing respiratory symptoms and diseases among children in homes that use a wood stove had disparate results. One study found that a multi-faceted intervention approach, which included stove and ventilation remediation and household education, led to decreases in parent-reported respiratory symptoms, respiratory visits, and school absences.¹⁶⁶ In contrast, another study did not observe meaningful differences in lower respiratory tract infections after implementing low-cost education and air filtration interventions.¹⁶⁷

3.4 Impacts of Residential Retrofits on Indoor Air Quality and Health

Below we discuss the impacts of residential retrofits and upgrades—including energy efficiency and weatherization retrofits (**Section 3.4.1**), ventilation and filtration retrofits (**Section 3.4.2**), electrification of fossil-fuel-powered combustion appliances (**Section 3.4.3**) and healthy homes programs (**Section 3.4.4**)—on indoor air quality and human health. Efforts aimed to support residential retrofits in Maryland are discussed in **Chapter 5**.

¹⁶⁴ Singleton, R., Salkoski, A. J., Bulkow, L., Fish, C., Dobson, J., Albertson, L., Skarada, J., Kovesi, T., McDonald, C., Hennessy, T. W., & Ritter, T. (2017). Housing characteristics and indoor air quality in households of Alaska Native children with chronic lung conditions. *Indoor Air*, 27(2), 478–486. <https://doi.org/10.1111/ina.12315>

¹⁶⁵ White, A. J., Teitelbaum, S. L., Stellman, S. D., Beyea, J., Steck, S. E., Mordukhovich, I., McCarty, K. M., Ahn, J., Rossner, P., Santella, R. M., & Gammon, M. D. (2014). Indoor air pollution exposure from use of indoor stoves and fireplaces in association with breast cancer: A case-control study. *Environmental Health*, 13(1), 108. <https://doi.org/10.1186/1476-069X-13-108>

¹⁶⁶ Singleton, R., Salkoski, A. J., Bulkow, L., Fish, C., Dobson, J., Albertson, L., Skarada, J., Ritter, T., Kovesi, T., & Hennessy, T. W. (2018). Impact of home remediation and household education on indoor air quality, respiratory visits and symptoms in Alaska Native children. *International Journal of Circumpolar Health*, 77(1), 1422669. <https://doi.org/10.1080/22423982.2017.1422669>

¹⁶⁷ Walker, E. S., Semmens, E. O., Belcourt, A., Boyer, B. B., Erdei, E., Graham, J., Hopkins, S. E., Lewis, J. L., Smith, P. G., Ware, D., Weiler, E., Ward, T. J., & Noonan, C. W. (2022). Efficacy of Air Filtration and Education Interventions on Indoor Fine Particulate Matter and Child Lower Respiratory Tract Infections among Rural U.S. Homes Heated with Wood Stoves: Results from the KidsAIR Randomized Trial. *Environmental Health Perspectives*, 130(4), 047002. <https://doi.org/10.1289/EHP9932>

3.4.1 Energy Efficiency and Weatherization

Residential energy-efficiency retrofits are often offered through governmental and utility programs, and require site-specific audits to identify measures appropriate for a specific home. Measures frequently include replacements of air conditioning and filtration systems, weatherization measures such as insulation and air sealing measures, and installation of energy-efficient home appliances.¹⁶⁸ While concerns have been raised regarding the impact of air sealing measures on the health and safety of residents,¹⁶⁹ many retrofit programs have required existing or retrofitted mechanical ventilation systems to meet current standards.¹⁷⁰ The specific interactions of housing design, materials used, occupant behaviors, outdoor air, and the changing climate all ultimately influence the health risks of energy efficiency interventions and zero net energy homes.¹⁷¹

Broadly, energy efficiency retrofits can affect indoor environmental quality parameters including temperature, humidity, and air pollutant concentrations.¹⁷² In tightly sealed homes without the availability or utilization of mechanical or passive ventilation measures (e.g., opening windows), indoor air pollutant concentrations may dramatically increase during certain activities (e.g., cooking) when concentrations may have a slow rate of decay in the home.¹⁷³ A review of studies evaluating the influence of residential energy efficiency retrofits on indoor air quality and self-reported comfort and health symptoms found mixed results. Some studies reported decreases in average indoor concentrations of NO₂ and volatile organic compounds (VOCs) (except for formaldehyde) after retrofits, while others reported increases in the same compounds after retrofits. Studies reported that indoor radon and formaldehyde concentrations increased after retrofits that did not include whole-house mechanical

¹⁶⁸ Francisco, P. W. (2016). Indoor Air Quality in Residential Energy Retrofits. *ASHRAE Journal*, 58(6), 80+. Gale Academic OneFile.

¹⁶⁹ NASEM (National Academies of Sciences, Engineering, and Medicine. (2011). Climate Change, the Indoor Environment, and Health. <https://doi.org/10.17226/13115>

¹⁷⁰ Francisco, P. W. (2016). Indoor Air Quality in Residential Energy Retrofits. *ASHRAE Journal*, 58(6), 80+. Gale Academic OneFile.

¹⁷¹ Hemsath, T. L., Walburn, A., Jameton, A., & Gulsvig, M. (2012). A review of possible health concerns associated with zero net energy homes. *Journal of Housing and the Built Environment*, 27(3), 389–400.

¹⁷² Fisk, W. J., Singer, B. C., & Chan, W. R. (2020). Association of residential energy efficiency retrofits with indoor environmental quality, comfort, and health: A review of empirical data. *Building and Environment*, 180, 107067. <https://doi.org/10.1016/j.buildenv.2020.107067>

¹⁷³ Militello-Hourigan, R. E., & Miller, S. L. (2018). The impacts of cooking and an assessment of indoor air quality in Colorado passive and tightly constructed homes. *Building and Environment*, 144, 573–582. <https://doi.org/10.1016/j.buildenv.2018.08.044>

ventilation.¹⁷⁴ Another study relying on modeling the impact of energy and ventilation retrofits on indoor air quality found that indoor air pollutant concentrations were reduced even with a wide variety of activities, while retrofits without ventilation resulted in increases in PM_{2.5} and NO₂ for some households.¹⁷⁵ This indicates that sealing a building envelope can negatively influence air quality without properly controlled ventilation measures, so careful consideration and proper education are needed when energy efficiency retrofits are implemented. Sufficient ventilation is an important consideration when implementing energy efficiency retrofits. In this context it is important to point out that the weatherization programs of Maryland's Department of Housing and Community Development strictly follow the ventilation standards of the American Society of Heating, Refrigeration, and Air-conditioning Engineers.¹⁷⁶

A recent review found self-reported perceived comfort and general health tend to improve after energy efficiency retrofits, while changes in asthma-related improvements were mixed pre- and post-retrofit.¹⁷⁷ Occupant reports of dampness and mold nearly always decreased after retrofits, and self-reported thermal comfort, non-asthma respiratory symptoms, general health, and mental health generally improved after retrofits. Additionally, given the variety of study designs and differences in reported results across studies, it was not possible to evaluate the influence of *specific* energy efficiency interventions on indoor air quality and health here.¹⁷⁸

Two studies modeled changes in indoor air pollutant concentrations from retrofits and translated these findings into health impacts and associated health costs. One study modeled indoor PM_{2.5} associated with residential energy-efficiency retrofits and PM_{2.5}-related health impacts and costs in a multifamily building in Boston, Massachusetts, comparing health savings and retrofit-related savings. Weatherization retrofits without ventilation or filtration resulted in health costs that far exceeded energy savings and population-level health savings, due to the increase in indoor PM_{2.5}. Meanwhile, weatherization paired with ventilation and filtration retrofits offered the largest savings overall (Underhill et al., 2020). A more recent

¹⁷⁴ Fisk, W. J., Singer, B. C., & Chan, W. R. (2020). Association of residential energy efficiency retrofits with indoor environmental quality, comfort, and health: A review of empirical data. *Building and Environment*, 180, 107067. <https://doi.org/10.1016/j.buildenv.2020.107067>

¹⁷⁵ Underhill, L. J., Fabian, M. P., Vermeer, K., Sandel, M., Adamkiewicz, G., Leibler, J. H., & Levy, J. I. (2018). Modeling the resiliency of energy-efficient retrofits in low-income multifamily housing. *Indoor Air*, 28(3), 459–468. <https://doi.org/10.1111/ina.12446>

¹⁷⁶ Nicola Tran, DHCD, personal communication with Arjun Makhijani, IEER, December 19, 2022

¹⁷⁷ Fisk, W. J., Singer, B. C., & Chan, W. R. (2020). Association of residential energy efficiency retrofits with indoor environmental quality, comfort, and health: A review of empirical data. *Building and Environment*, 180, 107067. <https://doi.org/10.1016/j.buildenv.2020.107067>

¹⁷⁸ Ibid.

study, also focused in Boston, Massachusetts, evaluated modeled indoor air quality and pediatric asthma exacerbation instances to evaluate the potential impacts of different energy retrofits in affordable housing.¹⁷⁹ The authors reported that modeled retrofit scenarios resulted in improved overall health outcomes and healthcare cost savings when energy-saving sealing retrofits were coupled with mechanical ventilation. These retrofits resulted in healthcare cost savings of \$200 annually for families in scenarios with indoor exposures to tobacco smoke and gas-stove cooking. Meanwhile, without mechanical ventilation, air sealing retrofits alone in the same households would result in an *increase* of nearly \$200 annually in healthcare utilization costs.¹⁸⁰

Additionally, studies note that combinations of interventions such as weatherization, healthy home interventions (discussed in **Section 3.4.4**), and broader educational efforts can improve childhood asthma control.¹⁸¹ In sum, energy efficiency retrofits serve as an important tool aimed to meet climate goals. Coupled air sealing, mechanical ventilation and filtration, and educational efforts can allow a controlled level of air change to balance addressing both energy efficiency and indoor air quality goals and can result in simultaneous benefits for climate and public health.

3.4.2 Household Ventilation and Filtration

The studies reviewed here indicated that, in practice, increasing household ventilation may not unequivocally lead to indoor air quality improvements. One study found that ventilation resulted in reductions in average indoor/outdoor air pollutant ratios across a range of pollutants (PM, ozone, NO₂, CO₂, CO, formaldehyde).¹⁸² Another study found that both exhaust ventilation and exhaust ventilation with enhanced filtration substantially reduced indoor PM_{2.5}.¹⁸³ In contrast, some researchers found that high ventilation rates in residences in urban areas may have negative effects on respiratory health due to the infiltration of outdoor air

¹⁷⁹ Tieskens, K. F., Milando, C. W., Underhill, L. J., Vermeer, K., Levy, J. I., & Fabian, M. P. (2021). The impact of energy retrofits on pediatric asthma exacerbation in a Boston multi-family housing complex: A systems science approach. *Environmental Health*, 20(1), 14. <https://doi.org/10.1186/s12940-021-00699-x>

¹⁸⁰ Ibid.

¹⁸¹ Breyse, J., Dixon, S., Gregory, J., Philby, M., Jacobs, D. E., & Krieger, J. (2014). Effect of Weatherization Combined With Community Health Worker In-Home Education on Asthma Control. *American Journal of Public Health*, 104(1), e57–e64. <https://doi.org/10.2105/AJPH.2013.301402>

¹⁸² Kang, I., McCreery, A., Azimi, P., Gramigna, A., Baca, G., Abromitis, K., Wang, M., Zeng, Y., Scheu, R., Crowder, T., Evens, A., & Stephens, B. (2022). Indoor air quality impacts of residential mechanical ventilation system retrofits in existing homes in Chicago, IL. *Science of The Total Environment*, 804, 150129. <https://doi.org/10.1016/j.scitotenv.2021.150129>

¹⁸³ Singer, B. C., Pass, R. Z., Delp, W. W., Lorenzetti, D. M., & Maddalena, R. L. (2017). Pollutant concentrations and emission rates from natural gas cooking burners without and with range hood exhaust in nine California homes. *Building and Environment*, 122, 215–229. <https://doi.org/10.1016/j.buildenv.2017.06.021>

pollution indoors.¹⁸⁴ Further, two studies from Lawrence Berkeley National Laboratory found that infiltration and intermittent ventilation can increase indoor air pollution concentrations under some conditions and that increasing mixing in most homes, i.e., the variability of pollutants from room to room, may not benefit average indoor air quality.^{185, 186}

In a study of 70 homes, scientists found that houses in compliance with California's mechanical ventilation requirements can be simultaneously built to stringent efficiency standards and maintain indoor air quality compared to households built prior to newer mechanical ventilation requirements.¹⁸⁷ Several studies further indicated that high-quality ventilation systems should be prioritized when conducting energy retrofits or upgrades. One study found that energy retrofits that are not coupled with ventilation retrofits may lead to elevated levels of PM_{2.5} or NO₂, especially in homes with heavy cooking or smoking activities.¹⁸⁸ Another study found that modeled homes that saved energy by reducing the flow of outdoor air into the indoor environment led to increases in exposure concentrations.¹⁸⁹ Further, a study of high-performance green homes,¹⁹⁰ reported that very airtight homes are particularly liable to design, installation, and operation faults of mechanical ventilation systems.

¹⁸⁴ Carlton, E. J., Barton, K., Shrestha, P. M., Humphrey, J., Newman, L. S., Adgate, J. L., Root, E., & Miller, S. (2019). Relationships between home ventilation rates and respiratory health in the Colorado Home Energy Efficiency and Respiratory Health (CHEER) study. *Environmental Research*, 169, 297–307.

<https://doi.org/10.1016/j.envres.2018.11.019>

¹⁸⁵ Sherman, M. H., Logue, J. M., & Singer, B. C. (2011). Infiltration effects on residential pollutant concentrations for continuous and intermittent mechanical ventilation approaches. *HVAC&R Research*, 17(2), 159–173.

<https://doi.org/10.1080/10789669.2011.543258>

¹⁸⁶ Sherman, M., & Walker, I. (2010). Impacts of Mixing on Acceptable Indoor Air Quality in Homes. *HVAC&R Research*, 16(3), 315–329. <https://doi.org/10.1080/10789669.2010.10390907>

¹⁸⁷ Singer, B. C., Chan, W. R., Kim, Y., Offermann, F. J., & Walker, I. S. (2020). Indoor air quality in California homes with code-required mechanical ventilation. *Indoor Air*, 30(5), 885–899. <https://doi.org/10.1111/ina.12676>

¹⁸⁸ Underhill, L. J., Fabian, M. P., Vermeer, K., Sandel, M., Adamkiewicz, G., Leibler, J. H., & Levy, J. I. (2018). Modeling the resiliency of energy-efficient retrofits in low-income multifamily housing. *Indoor Air*, 28(3), 459–468. <https://doi.org/10.1111/ina.12446>

¹⁸⁹ Walker, I., Less, B., Lorenzetti, D., & Sohn, M. D. (2021). Development of Advanced Smart Ventilation Controls for Residential Applications. *Energies*, 14(17), 5257. <https://doi.org/10.3390/en14175257>

¹⁹⁰ Less, B., Mullen, N., Singer, B., & Walker, I. (2015). Indoor air quality in 24 California residences designed as high-performance homes. *Science and Technology for the Built Environment*, 21(1), 14–24. <https://doi.org/10.1080/10789669.2014.961850>

Several studies reviewed here find that mechanical ventilation and filtration may lead to health benefits.^{191, 192} For example, one study found that increased home ventilation was associated with improved respiratory metrics although associations were stronger in healthy populations compared to the population with asthma or asthma-like symptoms.¹⁹³ Another study found that home ventilation treatment significantly reduced the risk of death, hospitalizations, and emergency room visits in medicare beneficiaries with chronic obstructive pulmonary disease and chronic respiratory failure.¹⁹⁴

Two studies further indicated that non-mechanical ventilation interventions, such as opening windows and doors, may lead to both indoor air quality and health benefits. For example, one study found that venting the indoor environment by opening windows and doors substantially reduced VOC concentrations and another study found that pregnant women who did not report the use of frequent window ventilation (i.e., had their windows open for less than half the day) had an increased risk of adverse birth outcomes.^{195, 196} However, these non-mechanical ventilation interventions are likely not a permanent solution for Marylanders and may only be practical during the shoulder seasons, i.e., spring and fall, when heating and air conditioning systems are used less frequently or not at all.

Although national data for how many homes have proper stove ventilation is lacking, researchers have found that gas stoves without properly vented exhaust hoods are common in inner-city households, including in Baltimore. Current literature also indicates that improved mechanical ventilation and filtration can allow a controlled level of air change that results in improved indoor air quality within the home. Such improvements are health

¹⁹¹ Carrer, P., Wargocki, P., Fanetti, A., Bischof, W., De Oliveira Fernandes, E., Hartmann, T., Kephelopoulou, S., Palkonen, S., & Seppänen, O. (2015). What does the scientific literature tell us about the ventilation–health relationship in public and residential buildings? *Building and Environment*, 94, 273–286. <https://doi.org/10.1016/j.buildenv.2015.08.011>

¹⁹² Zhao, D., Azimi, P., & Stephens, B. (2015). Evaluating the Long-Term Health and Economic Impacts of Central Residential Air Filtration for Reducing Premature Mortality Associated with Indoor Fine Particulate Matter (PM_{2.5}) of Outdoor Origin. *International Journal of Environmental Research and Public Health*, 12(7), 8448–8479. <https://doi.org/10.3390/ijerph120708448>

¹⁹³ Humphrey, J. L., Barton, K. E., Man Shrestha, P., Carlton, E. J., Newman, L. S., Dowling Root, E., Adgate, J. L., & Miller, S. L. (2020). Air infiltration in low-income, urban homes and its relationship to lung function. *Journal of Exposure Science & Environmental Epidemiology*, 30(2), 262–270. <https://doi.org/10.1038/s41370-019-0184-8>

¹⁹⁴ Frazier, W. D., Murphy, R., & van Eijndhoven, E. (2021). Non-invasive ventilation at home improves survival and decreases healthcare utilization in medicare beneficiaries with Chronic Obstructive Pulmonary Disease with chronic respiratory failure. *Respiratory Medicine*, 177, 106291. <https://doi.org/10.1016/j.rmed.2020.106291>

¹⁹⁵ Kristensen, K., Lunderberg, D. M., Liu, Y., Misztal, P. K., Tian, Y., Arata, C., Nazaroff, W. W., & Goldstein, A. H. (2019). Sources and dynamics of semivolatile organic compounds in a single-family residence in northern California. *Indoor Air*, ina.12561. <https://doi.org/10.1111/ina.12561>

¹⁹⁶ Ghosh, J. K. C., Wilhelm, M., & Ritz, B. (2013). Effects of Residential Indoor Air Quality and Household Ventilation on Preterm Birth and Term Low Birth Weight in Los Angeles County, California. *American Journal of Public Health*, 103(4), 686–694. <https://doi.org/10.2105/AJPH.2012.300987>

relevant, reducing the risk of respiratory diseases, such as asthma in Baltimore City children.¹⁹⁷

3.4.3 Electrification of Fossil Fuel-Powered Cooking and Heating Appliances

Low-energy and energy-efficient homes, retrofits, and low-carbon requirements for housing are being increasingly established in the United States to help meet near-term climate goals. As a result, the question of how electrification measures impact indoor air quality and health has become increasingly important, especially for those populations most vulnerable to indoor air pollution (**Section 3.2**).

A range of electric alternatives to fossil fuel-powered appliances are available and increasingly used in the United States today. Furnaces and boilers powered by natural gas, propane, or heating oil can be replaced by ground- or air-source heat pumps; gas-powered water heaters can be replaced by an electric equivalent; and gas-powered ovens and stove tops can be replaced with electric range ovens and induction cooktops, respectively.^{198, 199, 200}

Electrification of fossil fuel-powered heating and cooking appliances has become an increasingly popular climate change mitigation strategy.²⁰¹ In the United States, buildings account for 40 percent of the country's energy use-related greenhouse gas emissions, with 46 percent of all U.S. households using natural gas as their main heating fuel.^{202, 203} In Maryland this value is slightly lower, with 43 percent of all households using natural gas as their main heating fuel.²⁰⁴ Similarly, 38 percent of households in the U.S. (40 percent in Maryland) use a

¹⁹⁷ Breyse, P. N., Diette, G. B., Matsui, E. C., Butz, A. M., Hansel, N. N., & McCormack, M. C. (2010). Indoor Air Pollution and Asthma in Children. *Proceedings of the American Thoracic Society*, 7(2), 102–106.

<https://doi.org/10.1513/pats.200908-083RM>

¹⁹⁸ Gerdes, J. (2020, July 5). So, What Exactly Is Building Electrification?

<https://www.greentechmedia.com/articles/read/so-what-exactly-is-building-electrification>

¹⁹⁹ Hopkins, Takahashi, Glick, & Whited. (2018). Decarbonization of Heating Energy Use in California Buildings. Technology, Markets, Impacts, and Policy Solutions.

<https://www.californiageo.org/wp-content/uploads/Decarbonization-of-heating-in-CA-Bldgs-Synapse-2018.pdf>

²⁰⁰ Deetjen, T. A., Walsh, L., & Vaishnav, P. (2021). US residential heat pumps: The private economic potential and its emissions, health, and grid impacts. *Environmental Research Letters*, 16(8), 084024.

<https://doi.org/10.1088/1748-9326/ac10dc>

²⁰¹ Ibid.

²⁰² U.S. EIA (Energy Information Administration). (2022, June). Highlights for appliances in U.S. homes by state, 2020. <https://www.eia.gov/consumption/residential/data/2020/state/pdf/State%20Appliances.pdf>

²⁰³ Gerdes, J. (2020, July 5). So, What Exactly Is Building Electrification?

<https://www.greentechmedia.com/articles/read/so-what-exactly-is-building-electrification>

²⁰⁴ Maryland data from the 2021 American Community Survey, Table S2504 at

<https://data.census.gov/table?q=+Maryland+housing&tid=ACSST1Y2021.S2504>.

natural gas appliance for cooking.²⁰⁵ As natural gas furnaces are the most common space heating appliance in the U.S., the replacement of fuel-powered furnaces (and boilers) with heat pumps would substantially decrease the number of natural gas appliances used for residential heating.²⁰⁶

The proportion of households that rely on fossil fuels for heating and cooking also varies by demographic factors such as income, with low-income households relying on fossil fuel-based appliances at a higher rate than higher-income households.^{207, 208} In Baltimore City, Maryland, for example, 63 percent of low-income households rely on natural gas as their main heating fuel compared to the national average of 46 percent in the U.S.,²⁰⁹ with only 31 percent of low-income households relying on electric-powered heating sources.²¹⁰ Therefore, the full replacement of gas-powered heating appliances with electric alternatives could also have important health and equity benefits.

Health-damaging air pollutants emitted during household fossil fuel combustion activities (e.g., cooking, heating) substantially contribute to indoor air pollution, exposure to which is associated with various adverse health outcomes (e.g., childhood asthma, lung disease, respiratory infections, cancer, increased risk of adverse pregnancy outcomes) (**Section 3.2** and **Section 3.3**). While the replacement of these appliances with electric-powered alternatives would not eliminate the byproducts generated by the substances being cooked (e.g., fumes from cooking oils),²¹¹ it would help to improve indoor air quality and subsequent health in the home by avoiding combustion-related emissions inherent to fossil fuel appliances altogether.²¹² Additionally, findings suggest that electrification of fossil fuel-based kitchen appliances would have substantial impacts not only on indoor air quality in the

²⁰⁵

U.S. EIA (Energy Information Administration). (2022, June). Highlights for appliances in U.S. homes by state, 2020. <https://www.eia.gov/consumption/residential/data/2020/state/pdf/State%20Appliances.pdf>

²⁰⁶ Ibid.

²⁰⁷ Maryland Office of People's Counsel. (2018). Maryland Low-Income Market Characterization Report. Energy Efficiency for All. <https://www-new.energyefficiencyforall.org/resources/maryland-low-income-market-characterization-report/>

²⁰⁸ U.S. EIA. (2020). Residential Energy Consumption Survey (RECS) State Data. <https://www.eia.gov/consumption/residential/data/2020/index.php?view=state>

²⁰⁹ Ibid.

²¹⁰ Maryland Office of People's Counsel. (2018). Maryland Low-Income Market Characterization Report. Energy Efficiency for All. <https://www-new.energyefficiencyforall.org/resources/maryland-low-income-market-characterization-report/>

²¹¹ Zhai, S. R., & Albritton, D. (2020). Airborne particles from cooking oils: Emission test and analysis on chemical and health implications. *Sustainable Cities and Society*, 52, 101845. <https://doi.org/10.1016/j.scs.2019.101845>

²¹² CARB. (2022). Combustion Pollutants & Indoor Air Quality. <https://ww2.arb.ca.gov/resources/documents/combustion-pollutants-indoor-air-quality>

kitchen but throughout the home.²¹³

This notion is supported by evidence in the peer-reviewed literature, summarized below, which suggests that indoor air pollution is reduced when cooking and heating (e.g., furnaces, boilers) appliances are electrified. It should be noted that the impacts of gas appliances are discussed above (**Section 3.3**), while here we discuss the direct comparison between different types of appliances to assess the benefits of electrification. For example, a California study found ultrafine particulate matter (PM_{1.0}) concentrations in homes with induction cooktops (particle count = 5,430 #/cm³) to be substantially lower than concentrations found in households using natural gas (particle count=231,583 #/cm³) burners.²¹⁴ Additionally, this same study found NO₂, NO, and NO_x concentrations in homes using gas powered appliances for cooking to be higher compared to homes using electric cooking appliances (gas vs. electric, respectively: NO₂ = 13.1 vs. 5.4 ppb; NO = 13.8 vs. 7.4 ppb; NO_x = 29.9 vs. 10.9 ppb).²¹⁵

These findings have important health implications. For example, PM_{1.0} exposure can impact health, largely due to the elevated health risks associated with exposure to particles of such a small size. When inhaled, PM_{1.0} is able to travel to smaller airways and alveoli within the body that larger particles cannot, and diffuse and deposit onto respiratory surfaces, accumulating in the lung and remaining there permanently. Over time, frequent and repeated exposure can overburden the pulmonary system, resulting in more severe local and systemic responses to exposure.²¹⁶ Therefore, reductions in ultrafine particulates in the home would help reduce health risks.

SELECT STUDIES CONDUCTED IN BALTIMORE CITY, MD

The use of unvented gas stoves in homes is common in urban areas like Baltimore City.²¹⁷ As increased indoor NO₂ concentrations are directly associated with gas stove

²¹³ Seals, B. A., & Krasner, A. (2020). Health Effects from Gas Stove Pollution. Rocky Mountain Institute, Physicians for Social Responsibility, Mothers Out Front, and Sierra Club.

²¹⁴ Less, B., Mullen, N., Singer, B., & Walker, I. (2015). Indoor air quality in 24 California residences designed as high-performance homes. *Science and Technology for the Built Environment*, 21(1), 14–24.

<https://doi.org/10.1080/10789669.2014.961850>

²¹⁵ Ibid.

²¹⁶ U.S. EPA. (2014). Particle Pollution Exposure [Collections and Lists].

<https://www.epa.gov/pmcourse/particle-pollution-exposure>

²¹⁷ Paulin, L. M., Diette, G. B., Scott, M., McCormack, M. C., Matsui, E. C., Curtin-Brosnan, J., Williams, D. L., Kidd-Taylor, A., Shea, M., Breyse, P. N., & Hansel, N. N. (2014). Home interventions are effective at decreasing indoor nitrogen dioxide concentrations. *Indoor Air*, 24(4), 416–424. <https://doi.org/10.1111/ina.12085>

use, replacement with electric alternatives would help mitigate the health impacts associated with fossil fuel combustion emissions. Peer-reviewed studies on electrification of home appliances in Baltimore City, while limited, support this notion, highlighting indoor gas stove use as a major contributor to elevated indoor pollutant concentrations, in this case NO₂.

A study published in 2014 found that replacing unvented gas stoves in Baltimore City homes with electric alternatives was associated with a 51 percent decrease in NO₂ concentrations in the kitchen and a 42 percent reduction in NO₂ in the bedroom.²¹⁸ This trend was observed for the majority of homes in the study, despite the concurrent (and varied) use of other fossil-fuelled appliances (e.g., furnaces). This suggests that unvented gas stove use is a major contributor to indoor NO₂ concentrations.

Findings from Paulin et al. (2017) identify gas stove use as a major contributor to indoor NO₂ concentrations. The authors found that each hour of kitchen appliance use in Baltimore City homes with gas stoves and furnaces was associated with an increase in 24-hour averaged indoor NO₂ concentration. NO₂ increased by 18 ppb overall, by as much as 25 ppb NO₂ in the winter season, and by as much as 35 ppb when windows were closed.²¹⁹ Findings from Paulin et al. (2017) also demonstrate that substantial pollutant reductions could be achieved when gas stoves are replaced with electric stove alternatives.

An earlier study, Hansel et al. (2008), focused on children's exposure in low-income homes (with 91 percent African American children), found the range of NO₂ concentrations in from 2.9 ppb to 394 ppb, the latter value being almost four times the EPA one-hour limit for outdoor air. The authors found that an increase in 20 ppb of NO₂ was associated with statistically significant increases of respiratory symptoms in children including wheezing, coughing without a cold, and waking up at night because of respiratory symptoms.

These findings are health relevant. Acute exposure to elevated levels of NO₂ can aggravate the respiratory system, leading to increased asthma exacerbations,

²¹⁸ Ibid.

²¹⁹ Paulin, L. M., Williams, D. 'Ann L., Peng, R., Diette, G. B., McCormack, M. C., Breyse, P., & Hansel, N. N. (2017). 24-h Nitrogen dioxide concentration is associated with cooking behaviors and an increase in rescue medication use in children with asthma. *Environmental Research*, 159, 118–123. <https://doi.org/10.1016/j.envres.2017.07.052>

respiratory symptoms (wheezing, coughing, difficulty breathing), and respiratory-related hospitalizations and emergency department visits.²²⁰ Similarly, chronic exposure to elevated levels of NO₂ can contribute to the development of asthma and may increase one's susceptibility to respiratory infections.²²¹ In fact, adverse health impacts associated with elevated NO₂ concentrations are observed in Paulin et al. (2017). The authors found children with asthma living in homes with elevated NO₂ concentrations reported increased use of overnight emergency inhalers in the evening following exposure.²²² More specifically, each ten-fold increase in the previous day's NO₂ concentration was associated with an increased odds of night time emergency inhaler use in children with asthma.²²³

Improvements to indoor air quality are associated with improvements in respiratory disease outcomes, such as asthma symptoms in Baltimore City children. A review focused on studies conducted by the Johns Hopkins Center for Childhood Asthma in the Urban Environment and other relevant epidemiologic studies suggest that reductions in PM, NO₂, and mouse allergens in the home are effective asthma management strategies.²²⁴ For example, for each 10 mg/m³ increase in indoor PM_{2.5-10} concentration, there was a 6 percent increase in the number of days a child experienced cough, wheeze, or chest tightness.²²⁵ Additionally, reductions in indoor PM_{2.5} concentrations were positively associated with both reductions in respiratory symptoms and rescue medication use. Results from the Baltimore Indoor

²²⁰ U.S. EPA. (2016). Basic Information about NO₂ [Overviews and Factsheets].

<https://www.epa.gov/no2-pollution/basic-information-about-no2>

²²¹ Ibid.

²²² Paulin, L. M., Williams, D. 'Ann L., Peng, R., Diette, G. B., McCormack, M. C., Breyse, P., & Hansel, N. N. (2017). 24-h Nitrogen dioxide concentration is associated with cooking behaviors and an increase in rescue medication use in children with asthma. *Environmental Research*, 159, 118–123.

<https://doi.org/10.1016/j.envres.2017.07.052>

²²³ Ibid.

²²⁴ Breyse, P. N., Diette, G. B., Matsui, E. C., Butz, A. M., Hansel, N. N., & McCormack, M. C. (2010). Indoor Air Pollution and Asthma in Children. *Proceedings of the American Thoracic Society*, 7(2), 102–106.

<https://doi.org/10.1513/pats.200908-083RM>

²²⁵ Ibid.

Environment Study of Asthma in Kids (BIESAK) also show that Baltimore City homes have high indoor NO₂ concentrations.^{226, 227} Higher NO₂ concentrations were associated with statistically significant increases in respiratory symptoms in preschool children with asthma. Additionally, higher NO₂ concentrations were found in homes with a gas stove (average of ~33 ppb) compared to households without a gas stove (average of ~17 ppb).²²⁸ These results suggest that modifications in the home to reduce PM and NO₂ levels, such as electrification of cooking appliances, for example, would be an effective asthma management strategy.^{229, 230}

3.4.4 Healthy Homes

Healthy home programs have been widely adopted across the United States by states and cities such as Maryland and Baltimore City, in an effort to improve the environmental quality inside the home.^{231, 232} Generally, the intended goal of a healthy homes program is to prevent, identify, and address environmental health and safety concerns in an effort to provide every person with a safe, clean, and healthy home that promotes their well being.²³³ Those most vulnerable to home health and safety hazards, including low-income households and adults and children with asthma, are often prioritized for healthy home programs.^{234, 235} The

²²⁶ Hansel, N. N., Breyse, P. N., McCormack, M. C., Matsui, E. C., Curtin-Brosnan, J., Williams, D. L., Moore, J. L., Cuhnan, J. L., & Diette, G. B. (2008). A longitudinal study of indoor nitrogen dioxide levels and respiratory symptoms in inner-city children with asthma. *Environmental Health Perspectives*, 116(10), 1428–1432.

<https://doi.org/10.1289/ehp.11349>

²²⁷ Breyse, P. N., Diette, G. B., Matsui, E. C., Butz, A. M., Hansel, N. N., & McCormack, M. C. (2010). Indoor Air Pollution and Asthma in Children. *Proceedings of the American Thoracic Society*, 7(2), 102–106.

<https://doi.org/10.1513/pats.200908-083RM>

²²⁸ Ibid.

²²⁹ Ibid.

²³⁰ Hansel, N. N., Breyse, P. N., McCormack, M. C., Matsui, E. C., Curtin-Brosnan, J., Williams, D. L., Moore, J. L., Cuhnan, J. L., & Diette, G. B. (2008). A longitudinal study of indoor nitrogen dioxide levels and respiratory symptoms in inner-city children with asthma. *Environmental Health Perspectives*, 116(10), 1428–1432.

<https://doi.org/10.1289/ehp.11349>

²³¹ GHHI. (2015, April 22). The Green & Healthy Homes Initiative. AsthmaCommunityNetwork.Org.

<https://www.asthmacommunitynetwork.org/node/15680>

²³² MD Department of Environmental Health. (2022). Pages—Healthy Homes. Maryland Healthy Homes Programs.

<https://health.maryland.gov/phpa/OEHFP/EH/Pages/default.aspx>

²³³ Ibid.

²³⁴ Ferguson, A. C., & Yates, C. (2016). Federal Enactment of Healthy Homes Legislation in the United States to Improve Public Health. *Frontiers in Public Health*, 4. <https://doi.org/10.3389/fpubh.2016.00048>

²³⁵ Mankikar, D., Campbell, C., & Greenberg, R. (2016). Evaluation of a Home-Based Environmental and Educational Intervention to Improve Health in Vulnerable Households: Southeastern Pennsylvania Lead and

particular focus for this chapter are programs that specifically integrate energy efficiency and energy use retrofits, including decarbonization, into the intervention's design.

A major health concern often targeted in healthy home programs is the prevalence of childhood asthma and risk of exposure to household asthma triggers, especially in low-income households that are disproportionately impacted. The Lowell Healthy Homes Program in Massachusetts, for example, implemented in-home interventions from 2009 to 2012 aimed at reducing and/or eliminating household allergens and asthma triggers in low-income households that have children with asthma.²³⁶ Home visits and environmental assessments helped identify any household asthma triggers and were used to inform household-specific interventions. Remediation plans included interventions such as pest management, commercial cleaning, providing healthy cleaning equipment and supplies (e.g., green cleaning chemicals), education, and, on occasion, structural interventions. Results from this study demonstrated a statistically significant health improvement between baseline and follow-up visits. Participants had lower asthma-related symptoms (e.g., wheezing, asthma attacks) and lower health care utilization (e.g., emergency department visits, hospitalizations) post-intervention.²³⁷

These same improvements in asthma-related health outcomes, symptoms, and healthcare utilizations from interventions aimed at reducing asthma triggers were observed in healthy home programs in Michigan, New York, and Southeastern Pennsylvania.^{238,239} For example, a study conducted in New York evaluated the impact of state-funded healthy home interventions on asthma outcomes in adults and children.²⁴⁰ The New York State (NYS) Healthy Neighborhoods Program (HNP) operates in communities with a higher burden of

Healthy Homes Program. *International Journal of Environmental Research and Public Health*, 13(9), 900.

<https://doi.org/10.3390/ijerph13090900>

²³⁶ Turcotte, D. A., Alker, H., Chaves, E., Gore, R., & Woskie, S. (2014). Healthy Homes: In-Home Environmental Asthma Intervention in a Diverse Urban Community. *American Journal of Public Health*, 104(4), 665–671.

<https://doi.org/10.2105/AJPH.2013.301695>

²³⁷ Ibid.

²³⁸ Largo, T. W., Borgialli, M., Wisinski, C. L., Wahl, R. L., & Priem, W. F. (2011). Healthy Homes University: A Home-Based Environmental Intervention and Education Program for Families with Pediatric Asthma in Michigan. *Public Health Reports*, 126(1_suppl), 14–26. <https://doi.org/10.1177/00333549111260S104>

²³⁹ Mankikar, D., Campbell, C., & Greenberg, R. (2016). Evaluation of a Home-Based Environmental and Educational Intervention to Improve Health in Vulnerable Households: Southeastern Pennsylvania Lead and Healthy Homes Program. *International Journal of Environmental Research and Public Health*, 13(9), 900.

<https://doi.org/10.3390/ijerph13090900>

²⁴⁰ Reddy, A. L., Gomez, M., & Dixon, S. L. (2017a). An Evaluation of a State-Funded Healthy Homes Intervention on Asthma Outcomes in Adults and Children. *Journal of Public Health Management and Practice*, 23(2), 219–228.

<https://doi.org/10.1097/PHH.0000000000000530>

housing-related adverse health impacts and associated risk factors.^{241,242} Interventions within this program that were aimed at reducing and/or eliminating asthma triggers were found to significantly improve environmental conditions in the home, as well as improve self-reported asthma symptoms, self-management of asthma symptoms, health care visits, and asthma morbidity outcomes.^{243,244} This program also significantly reduced tobacco smoke, fire, lead, indoor air pollution, pests, and mold hazards.²⁴⁵

3.5 Summary

Electrification can eliminate combustion-related emissions associated with residential space and water heating and cooking appliances, including air pollutants such as PM_{2.5}, NO_x, CO, benzene, and formaldehyde which are associated with a variety of adverse cardiovascular and respiratory health effects.

Studies have shown that gas-based appliances can leak, even when they are not in use—contributing to hazardous air pollutant concentrations indoors. Indoor combustion of fossil fuels and wood in cooking and heating appliances contributes to poor indoor air quality, particularly when they are vented indoors (e.g., gas cooking stoves). Appliances reliant on electricity do not require indoor combustion and therefore do not emit combustion-related emissions. However, the use of electric or induction ranges and ovens may contribute to indoor air pollutant emissions related to types of foods being cooked. Ventilation can also improve indoor air quality benefits when electric stoves and ovens or induction ranges are used.

Low-income communities and communities of color tend to be disproportionately impacted by and are more susceptible to environmental risk factors and adverse health outcomes. Because Maryland has a higher fraction of people of color than the national average and

²⁴¹ Ibid.

²⁴² Reddy, A. L., Gomez, M., & Dixon, S. L. (2017b). The New York State Healthy Neighborhoods Program: Findings From an Evaluation of a Large-Scale, Multisite, State-Funded Healthy Homes Program. *Journal of Public Health Management and Practice*, 23(2), 210–218. <https://doi.org/10.1097/PHH.0000000000000529>

²⁴³ Gomez, M., Reddy, A. L., Dixon, S. L., Wilson, J., & Jacobs, D. E. (2017). A Cost-Benefit Analysis of a State-Funded Healthy Homes Program for Residents With Asthma: Findings From the New York State Healthy Neighborhoods Program. *Journal of Public Health Management and Practice*, 23(2), 229–238. <https://doi.org/10.1097/PHH.0000000000000528>

²⁴⁴ Reddy, A. L., Gomez, M., & Dixon, S. L. (2017a). An Evaluation of a State-Funded Healthy Homes Intervention on Asthma Outcomes in Adults and Children. *Journal of Public Health Management and Practice*, 23(2), 219–228. <https://doi.org/10.1097/PHH.0000000000000530>

²⁴⁵ Reddy, A. L., Gomez, M., & Dixon, S. L. (2017b). The New York State Healthy Neighborhoods Program: Findings From an Evaluation of a Large-Scale, Multisite, State-Funded Healthy Homes Program. *Journal of Public Health Management and Practice*, 23(2), 210–218. <https://doi.org/10.1097/PHH.0000000000000529>

Baltimore City has a higher poverty rate than the national average, its residents may be particularly vulnerable to degraded indoor air quality.

Energy efficiency retrofits serve as an important tool aimed to meet climate goals. Programs and interventions can be structured to achieve simultaneous climate and health benefits. Coupled air sealing, mechanical ventilation and filtration, and electrification efforts can improve both energy efficiency and indoor air quality resulting in simultaneous benefits for climate and public health. The research indicates that high-quality ventilation systems should be prioritized when conducting energy retrofits or upgrades to ensure that household ventilation is maintained or improved when energy retrofits are implemented. The greatest benefit will be derived when targeted programs are implemented carefully and focus on populations vulnerable to poor indoor air quality.

In **Chapter 4**, we examine a specific Maryland law that would entrench natural gas use, and leave low- and moderate income households with high bills and indoor air pollution that could be avoided with suitable electrification and ventilation strategies.



4.0 Impacts of Natural Gas Investment

4.1 Introduction

Continued reliance on natural gas presents a complex economic, environmental justice, and climate dilemma for the state of Maryland. The Climate Solutions Now Act establishes climate targets that are among the most ambitious in the world: 60 percent greenhouse gas emission reductions by 2031 relative to 2006, and a carbon-neutral economy by 2045.²⁴⁶

At the same time, the 2013 Strategic Infrastructure Development and Enhancement (STRIDE) law encourages utility investments in natural gas infrastructure into the 2040s. The law was created with the ostensible purpose of improving safety and reducing leaks. It authorized Maryland's Public Service Commission (PSC) to allow accelerated cost recovery for the replacement of existing natural gas distribution pipes with limited review, and bypassed the more rigorous rate-setting process, which normally also covers safety. (See **Section 4.3** below). Yet, the investments are allowed to be added to the rate base (after deducting the accelerated recovery), enabling utilities to earn a rate of return that they might not get in many cases if leaks were detected and repaired. These features incentivized natural gas companies to propose billions of dollars of pipe replacements without any quantitative estimate of leak reductions or safety improvements. By making natural gas infrastructure a more appealing investment, STRIDE :

- Locks in continued recovery of revenues from natural gas for decades even as the Climate Solutions Now Act requires the phasing out of fossil fuels;
- Implies continued use of gas infrastructure well after 2045 at great cost and in conflict with the Climate Solutions Now Act;
- Creates the risk of significant stranded costs as Maryland's residential and commercial sectors decarbonize.

A conflict is apparent between climate goals and continued large investments in natural gas infrastructure under STRIDE. In this chapter, we will explore climate imperatives, the potential for stranded costs given the ambitious goals of Maryland's 2022 Climate Solutions Act, and historical safety issues as they may be linked to the implementation of STRIDE. We will also refer to the more general health and safety imperatives associated with natural gas and the need to eliminate it from residential use, as discussed in **Chapter 3**.

²⁴⁶ Maryland General Assembly, Climate Solutions Now Act of 2022, Senate Bill 528, Effective Date June 1, 2022, at <https://mgaleg.maryland.gov/2022RS/bills/sb/sb0528E.pdf>

KEY FINDINGS

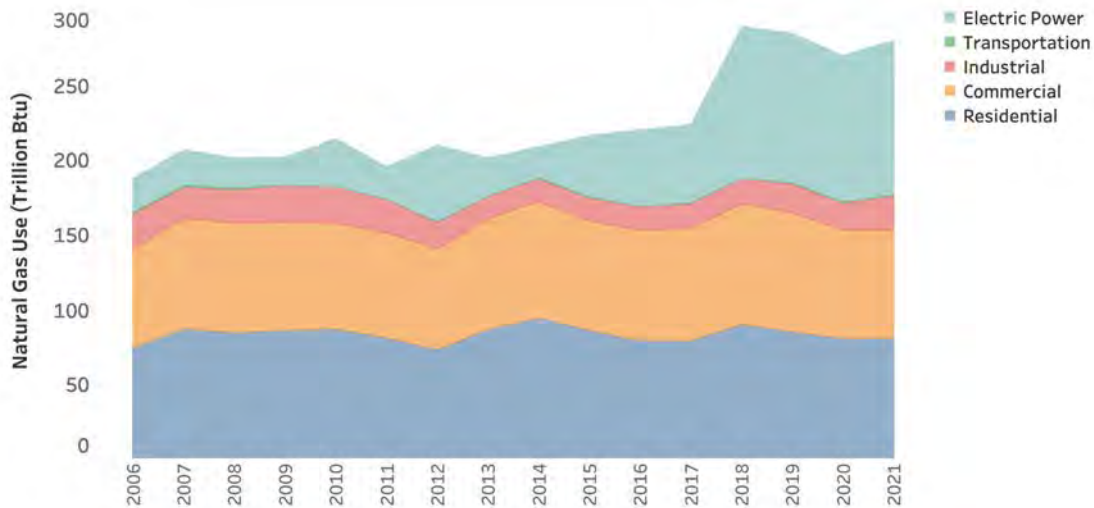
- STRIDE is in direct conflict with the 2022 Climate Solutions Now Act, which necessitates a near complete elimination of natural gas emissions in the building sector by 2045.
- Investments in gas infrastructure under STRIDE could result in a 30 percent increase in natural gas delivery costs for ratepayers by 2045.
- Low- and moderate-income renters are slower to electrify and therefore more likely to shoulder the cost of stranded gas assets, aggravating existing inequities and raising the need for bill assistance.
- Maintaining natural gas pipeline infrastructure in the hope of using synthetic gas is technologically uncertain, costly, and prolongs adverse impacts on public health, equity, and the environment.
- Approximately \$2 billion dollars of pipeline investment authorized under STRIDE have not resulted in a material reduction of the rate of serious accidents (defined as those causing serious injury or death).
- Prioritizing electrification in neighborhoods with leaks and other safety risks may provide greater public safety.

4.2 Direct Natural Gas Use in Maryland and Associated Emissions

It is useful to gain some perspective on the role of converting buildings from natural gas to electric space and water heating in Maryland's climate targets. The residential and commercial sectors account for more than 80 percent of Maryland's direct natural gas use.

Figure 4-1 shows natural gas use in Maryland from 2006, the baseline year for Maryland greenhouse gas accounting, to 2021 by sector. The energy to deliver the natural gas and leaks and losses are not shown in **Figure 4-1**.

Figure 4-1: Natural gas consumption in Maryland, by sector, in trillion BTU per year. *Source for natural gas data: U.S. Energy Information Administration*²⁴⁷



The main growth in natural gas use in Maryland has been for electricity generation. Despite the fact that electricity generation is currently the largest single use of natural gas, the combined direct use in the residential and commercial sectors—that is, in buildings—is the largest use of the fuel, representing about 55 percent of the total use and about 87 percent of all direct end-uses of natural gas (that is, excluding electricity generation). Thus, decarbonizing the buildings sector, and within that the residential sector (which represents more than half of the use in the buildings sector), is a critical part of meeting the emission reduction targets of the Climate Solutions Now Act.

Figure 4-2 shows the greenhouse gas emissions associated with natural gas end-uses in the residential and commercial sectors. Natural gas combustion produces CO₂, but methane also leaks through the entire lifecycle of natural gas, inclusive of production, processing, transmission and distribution. **Figure 4-2** shows the direct CO₂ emissions due to combustion as well as the CO₂-equivalent of methane leaks evaluated at the 20-year warming potential of

²⁴⁷ Natural Gas Consumption by End Use – Area: Maryland, Energy Information Administration, August 31, 2022, at https://www.eia.gov/dnav/ng/ng_cons_sum_dcu_SMD_a.htm The data were converted from cubic feet of natural gas to Btu using an average conversion factor of 1,040 Btu/cubic foot for all years.

84 (relative to CO₂ = 1).²⁴⁸ The assumed leak rate was 2.7 percent on an end-use basis.²⁴⁹ This includes leaks from the entire natural gas system up to the meter at the end-user, but does not include leaks inside homes and commercial establishments at the point of use, such as a gas cooking stove or oven or a gas water heater or gas furnace. As such, the emissions shown are likely an underestimate of the total.

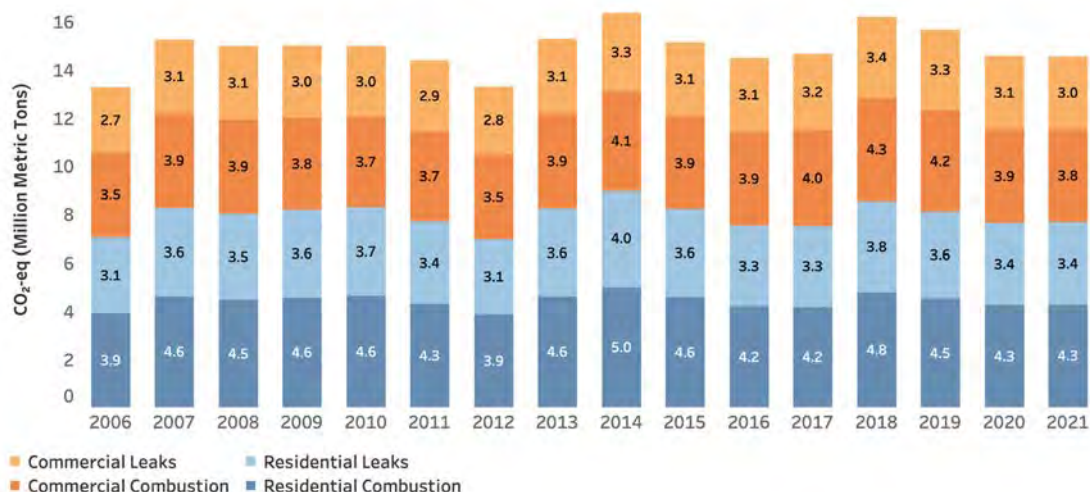


Figure 4-2: Residential and commercial sector CO₂-equivalent emissions due to natural gas use in Maryland, with methane leaks evaluated at a 20-year global warming potential. The leak rate of 2.7 percent is calculated from Alvarez et al. 2018.²⁵⁰

The direct CO₂ emissions attributable to combustion in the residential sector in 2021 were 4.3 million metric tons; the warming impact of the methane in natural gas leaks evaluated at its 20-year warming potential increases the total CO₂-equivalent emissions by almost 70 percent to 7.7 million metric tons. The commercial sector totals were only slightly smaller. The total

²⁴⁸ Maryland Greenhouse Gas Inventory for 2020, Maryland Department of Environment, September 24, 2022, at https://mde.maryland.gov/programs/air/ClimateChange/Documents/VIMAL/MD_2020_GHG_Inventory_2022-09-24.xlsx

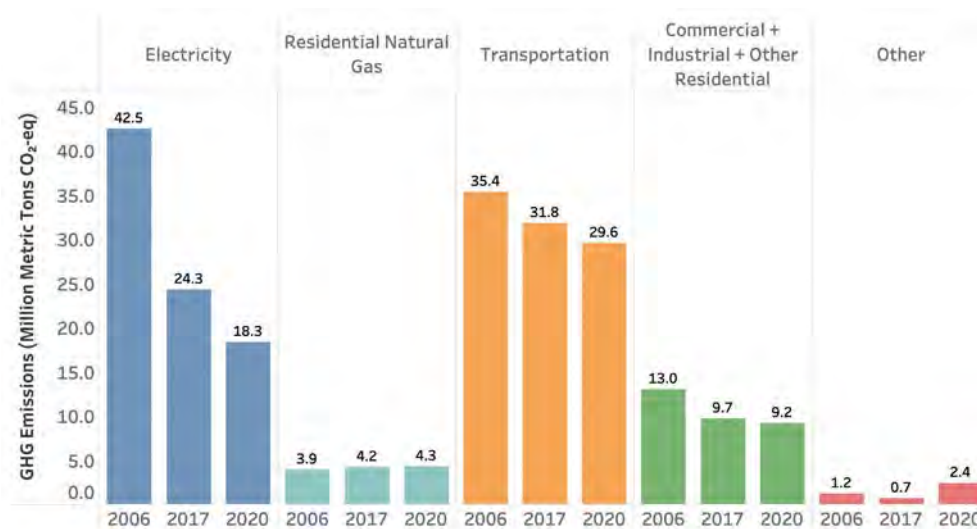
²⁴⁹ Natural Gas Consumption by End Use – Area: Maryland, Energy Information Administration, August 31, 2022, at https://www.eia.gov/dnav/ng/ng_cons_sum_dcu_SMD_a.htm In addition, the Climate Solutions Now Act requires calculation of the warming impact of methane using the 20-year global warming potential. Maryland General Assembly, Climate Solutions Now Act of 2022, Senate Bill 528, Effective Date June 1, 2022, at <https://mgaleg.maryland.gov/2022RS/bills/sb/sb0528E.pdf>

²⁵⁰ Ramón A. Alvarez et al., Assessment of methane emissions from the U.S. oil and gas supply chain, Science, Volume 361, July 13, 2018, at <https://www.science.org/doi/reader/10.1126/science.aar7204> gives a leak rate of 2.3 percent based on natural gas production and an overall methane leakage of 13 teragrams in 2015. Based on these estimates and a usage of 25 trillion cubic feet in that year, we estimate a leak rate based on usage of 2.7%.

methane leak impact of natural gas use in buildings (assuming it is entirely coincident with the residential plus commercial sectors) in 2017 was 5.7 million metric tons, or more than 8 percent of the reported energy-related greenhouse gas inventory, 70.7 million metric tons, for that year, conventionally calculated. Maryland has traditionally calculated the CO₂-equivalent of methane with its 100-year warming potential and included only in-state methane leaks in that calculation. The Climate Solutions Now Act of 2022 requires the Maryland Department of Environment to calculate the CO₂ equivalent of methane pollution using its 20-year warming potential.²⁵¹

Figure 4-3 shows the residential sector natural gas emissions in comparison to all of Maryland’s energy sector greenhouse gas emissions, calculated in the traditional way by the Maryland Department of Environment. Only the CO₂ component of residential natural gas is shown since the methane leak component is very small, as estimated by the Department.

Figure 4-3: Maryland greenhouse gas emissions in 2006 (baseline year), 2017, and 2020, by sector. *Source: Maryland Department of Environment.*²⁵²



²⁵¹ Maryland General Assembly, Climate Solutions Now Act of 2022, Senate Bill 528, Effective Date June 1, 2022, at <https://mgaleg.maryland.gov/2022RS/bills/sb/sb0528E.pdf>

²⁵² Maryland Department of Environment, Greenhouse Gas Inventory 2006 , 2017, at https://mde.maryland.gov/programs/air/ClimateChange/Documents/VIMAL/MD_2006_Base_Year_GHG_Emission_Inventory_20210610.xlsm, https://mde.maryland.gov/programs/air/ClimateChange/Documents/VIMAL/MD_2017_GHG_Emission_Inventory_20210610.xlsx and https://mde.maryland.gov/programs/air/ClimateChange/Documents/VIMAL/MD_2020_GHG_Inventory_2022-09-24.xlsx respectively. Note that these CO₂-eq values are based on a 100-year global warming potential (GWP) for methane. Maryland required the use of a 20-year warming potential under the Climate Solutions Now Act of 2022; the 20-year GWP is used in the rest of this chapter.

Natural gas use in the residential and commercial sectors has increased in absolute terms from about 139 trillion BTU in 2006 to 154 trillion BTU in 2017. Natural gas use in buildings has mainly fluctuated with the weather in recent years; it was 153 trillion BTU in 2021.

Continuing significant use of natural gas in the residential and commercial sectors is in conflict with the goals of Maryland's Climate Solutions Act. **Thus, by law, whatever the undepreciated amount of building-related pipeline replacement investments remain, they will likely have little value on January 1, 2046.** This is the classic situation of stranded costs. Indeed, most of the natural gas distribution system is likely to become a stranded cost well before that date, since rising rates will induce rapid conversion or heating from natural gas to electricity by all those who can afford it.

We first analyze the impact on rates of the 2013 law that allows advance recovery of pipeline investments and then address the broader question of the impact of rising rates and falling number of consumers using natural gas in Maryland.

4.3 Maryland's STRIDE Law

In September, 2010, a massive natural gas pipe explosion in San Bruno California triggered national concern over the safety of natural gas systems. As in many other states, Maryland's STRIDE law was passed in 2013 in response, in part at federal urging. STRIDE authorized significant investments supposedly to address leaking and potentially unsafe infrastructure in Maryland's natural gas system. In evaluating STRIDE, it is therefore important to understand whether the fundamental causes of the San Bruno accident relate in material ways to the Maryland situation. We will turn to the specifics of Maryland's gas infrastructure after examining the San Bruno accident briefly to illuminate the national events that followed.

4.3.1 The 2010 San Bruno Pipeline Explosion

The Pipeline Safety Trust Report described the September 9, 2010 explosion as follows:

The rupture produced a crater about 72 feet long by 26 feet wide. The section of pipe that ruptured, which was about 28 feet long and weighed about 3,000 pounds, was found 100 feet south of the crater. The released natural gas ignited, resulting in a fire that destroyed 38 homes and damaged 70. Eight people were killed, many were injured, and many more were evacuated from the area.²⁵³

²⁵³ Pipeline Safety Trust Report (2011)

https://pstrust.org/map-of-major-incidents/sanbruno/?doing_wp_cron=1655840790.7332940101623535156250

The National Transportation Safety Board oversees major transportation accidents, including natural gas pipelines (which transport natural gas). Its investigation into the San Bruno explosion concluded that the rupture was caused by a problem at the time of the installation of the pipe:

The National Transportation Safety Board’s investigation found that the rupture of Line 132 was caused by a fracture that originated in the partially welded longitudinal seam of one of six short pipe sections, which are known in the industry as “pups.” The fabrication of five of the pups in 1956 *would not have met generally accepted industry quality control and welding standards then in effect*, indicating that those standards were either overlooked or ignored. The weld defect in the *failed pup would have been visible when it was installed*. The investigation also determined that a sewer line installation in 2008 near the rupture did not damage the defective pipe.²⁵⁴

The Board Chair explicitly criticized lax regulation and far too much trust in the company without adequate verification of its assertions as contributing factors:

The NTSB investigation revealed that for years, PG&E exploited weaknesses in *a lax system of oversight*. We also identified *regulators that placed a blind trust in the companies that they were charged with overseeing—to the detriment of public safety*.

In the pipeline industry, there must be effective oversight and strong enforcement....In too many instances, the regulators in this case didn’t really know what was going on or require the operator to live up to their commitments.

For example, our investigators identified poor record-keeping, flawed assumptions in PG&E’s integrity management programs, a failure to increase safety on an aging pipe in a high-consequence area with remote control valves or in-line inspections, and inadequate drug and alcohol testing protocols.

....Ronald Regan [sic] famously said, “Trust but verify.” For government to do its job—safeguard the public—it cannot trust alone. It must verify through effective oversight.²⁵⁵

²⁵⁴ National Transportation Safety Board, Pacific Gas and Electric Company Natural Gas Transmission Pipeline Rupture and Fire San Bruno, California September 9, 2010: Accident Report, NTSB/PAR-11/01 PB2011-916501, August 30, 2011, p. x, italics added, at <https://www.nts.gov/investigations/accidentreports/reports/par1101.pdf>.

²⁵⁵ *Ibid.* p. 135, italics added.

A few things are critical to note about the causes of the accident in light of the national and state-level events that followed:

- The core problem that led to the explosion was the faulty installation of the pipe.
- While the pipe was 54 years old at the time of the explosion, specific deterioration of the section of the pipe due to aging of the section of the pipe was *not identified as a cause*. The Chair of the National Transportation Safety Board did imply that the utility should have replaced that section of pipe as part of its aging management for replacing pipes in a seismically active (“high consequence”) area (see the quote just above).
- The Board’s chair explicitly exhorted vigilant regulation and verification if regulatory bodies like the California Public Utilities Commission were to fulfill their responsibilities for public safety.

Exacerbating the catastrophe, the gas utility, PG&E, was unable to stop the flow of gas to the accident site for 1 hour and 35 minutes. This excess gas flow fueled the inferno adding to the destruction and the inability for 900 crew to extinguish the fire. The explosion also destroyed a water main pipe, hampering fire-fighting operations.

In brief, the 2010 San Bruno explosion was a catastrophe that commanded national attention, all the more so after the findings of the National Transportation Safety Board clearly fingered the company’s faulty installation of the pipe (“the failed pup would have been visible when it was installed”) as the cause, and inadequate oversight and regulation as contributory factors.

Almost simultaneously with the issuance of the findings of the National Transportation Safety Board, Ray LaHood, then-Secretary of Transportation, issued a broad “Call to Action” to address safety issues associated with, among other things, aging pipelines and improperly installed infrastructure. He called upon “all parties to step up efforts to identify high-risk pipelines and ensure that they are repaired or replaced.” State regulators and natural gas companies were, of course, included among those parties.²⁵⁶ While he mentioned other pre-San Bruno accidents, Secretary LaHood’s call was clearly linked to the San Bruno catastrophe, which was worse than accidents in the two prior years.

The San Bruno explosion, and the National Transportation Safety Board 2011 report on the accident, seemed to create an urgency about safety and replacement of aging pipeline infrastructure, even though the core cause was not aging, but blatantly faulty installation.

²⁵⁶ Ray LaHood, U.S. Department of Transportation Call to Action To Improve the Safety of the Nation’s Energy Pipeline System. Washington, D.C.: U.S. Department of Transportation, revised November 1, 2011 at <https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/docs/Action%20Plan%20Executive%20Version%201%20NOV%2011.pdf>

Even worse, as noted above, the National Transportation Safety Board said that “weld defect ...would have been visible when it was installed”; apparently no one, including the regulators, was doing the necessary job of verifying that the installation was safe. Even more remarkably, pipeline safety had actually improved since 1991, according to the press release that followed the San Bruno accident but preceded Secretary LaHood’s Call to Action by a few months:

Pipeline incidents resulting in serious injury or death are **down nearly 50 percent over the last 20 years**. In 1991, there were 67 such incidents compared to 36 in 2010, and an average of 42 per year over the last 10 years. However, a series of recent incidents have highlighted the need to address the nation’s aging pipeline infrastructure.²⁵⁷

Nonetheless, Secretary LaHood’s “Call to Action” urged pipeline owners and operators to make aggressive efforts to “conduct a comprehensive review of their oil and gas pipelines to identify areas of high risk and accelerate critical repair and replacement work.” In reviewing Maryland’s efforts in this regard, it is essential to keep in mind that the first step is to identify the areas of high risk. Moreover, while the focus on Secretary LaHood’s statement was on pipelines, improving safety, as is documented below, requires a focus on the causes of serious accidents, which may or may not involve the replacement of pipelines.

Congress passed legislation in 2012 on the matter and states began to take action. National spending on pipeline replacements skyrocketed after the legislation passed, as can be seen in **Table 4-1**. The result in Maryland was the 2013 STRIDE legislation.

²⁵⁷ “U.S Transportation Secretary Ray LaHood Announces Pipeline Safety Action Plan *U.S. DOT Initiates National Effort to Prevent Hazardous Pipeline Incidents*,” U.S. Department of Transportation Press Release, April 4, 2011 at <https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/docs/dot4111.pdf>

Table 4-1: U.S. Gas Utility Distribution Expenditures. Source: American Gas Association, Table 12-1.²⁵⁸

Period	Avg. Yearly Gas Utility Distribution Expenses, Billion \$	Percent Change From Prior Period
1972-1981	\$1.2	
1982-1991	\$2.9	133%
1992-2001	\$4.5	54%
2002-2012	\$5.2	16%
2013-2020	\$13.7	162%

Note: Values not adjusted for inflation.

4.3.2 Prelude to STRIDE

Neither natural gas safety nor pipeline replacement were new issues in 2013, when the STRIDE legislation was passed, or indeed, when the San Bruno accident put them on the national policy map. Safety has been tracked by the federal government; accidents involving serious injury or fatalities are investigated for causes and lessons learned by the National Transportation Safety Board (as occurred in the aftermath of the San Bruno accident). Safety is a central responsibility of gas utilities, and overseeing it and ensuring safety is part of the function of the Maryland Public Service Commission.

What was new in Maryland was the notion that pipeline replacement investments should not be decided during normal rate cases but that these investments could be initially recovered through surcharges on ratepayers on an expedited basis.

A 2011 application by Washington Gas (WGL), one of the three principal gas utilities in Maryland, provided a prelude to utilities' view by requesting an increase to rates in part to replace pipes. The Commission, in its final order, described the application as follows:

The Application, which was filed on April 15, 2011,... requested that the Commission approve rates and charges designed to increase the Company's Maryland annual operating revenues by \$30 million, or 5.9%... The Company claimed that its test year return fell below the return necessary for the Company to attract capital on reasonable terms. In addition to seeking a rate increase, the Company also asked us to approve an *Accelerated Pipe Replacement Plan* ("APRP"), a plan through which it would spend \$115 million

²⁵⁸ American Gas Association, Annual Construction Expenditures: Construction Expenditures by Type of Facility, 1972-2020, at <https://www.aga.org/contentassets/5d9888f793ad4508bb35cb6b5f2c1865/table12-1.pdf>

*over five years to replace its piping infrastructure and recover the costs through a surcharge.*²⁵⁹

In its Order deciding the case, the PSC approved the request in part and denied it in part. It approved recovery of safety and reliability expenditures already made as well as a slight increase in rates although “substantially less than the Company sought.” And in regard to replacement of pipe for safety and reliability and recovery of those costs through a surcharge, the PSC decided as follows:

Although we agree fully with the Company that safe and reliable infrastructure is the highest priority and that *it should accelerate its program to replace pipe, we decline to authorize a surcharge* for the recovery of future pipe replacement expenses. Based on the record in this case, we find that the Company has historically demonstrated the ability to replace the infrastructure when necessary to ensure safety and reliability, and that it can do so using traditional ratemaking procedures without compromising its ability to earn an appropriate return. The Company's witnesses confirm that WGL has the operational and financial ability to accelerate its existing pipe replacement program, and we authorize the Company to do so. But *the mere fact that the Company plans increased infrastructure investments does not justify a surcharge*, which would represent a fundamental shift from long-standing rate-making principles. *To the contrary, the record in this case demonstrates that the Company can invest significant amounts in infrastructure and can readily recover those costs in rates with an appropriate return.*²⁶⁰

Clearly, the PSC put “the highest priority” on safety and reliability of the gas infrastructure. It ordered recovery of those expenditures. It assessed the ability of the company to make the necessary investments based on its history and its standing in the markets; on that basis the PSC denied the request for a surcharge. That matter was at the heart of the 2013 STRIDE law.

²⁵⁹ In the matter of the Application of the Washington Gas Light Company for Authority to Increase its Existing Rates and Charges and to Revise its Terms and Conditions for Gas Service, Maryland Public Service Commission Order 84475, Rate Case 9267, November 14, 2011, (italics added), at https://webapp.psc.state.md.us/newIntranet/Casenum/NewIndex3_VOpenFile.cfm?FilePath=//Coldfusion/Case/num/9200-9299/9267/98.pdf

²⁶⁰ Ibid.

4.3.3 Features of the STRIDE Law²⁶¹

Maryland's 2013 Strategic Infrastructure Development and Enhancement (STRIDE) authorized the PSC to oversee replacement of existing natural gas distribution pipeline infrastructure and recover the cost, including a rate of return on investment, from ratepayers. Recovery via a surcharge, capped at \$2 per month per residential customer, was also permitted. The investment could be a "replacement" or "improvement" in the infrastructure; the one restriction was that the pipeline not connect to a new customer. The main feature of the bill, both for those who supported it and those who opposed it, was the ability of the utility to collect a surcharge from ratepayers even before the replacement pipeline is in service and without having to go through a normal rate case. In rate cases, recovery can occur only after the investment is in service. Only a part of the STRIDE investment is recovered via the surcharge, which is only the initial recovery that short-circuits the rate-case process. The rest is put into the rate base after the utility files a rate case.

Utilities proposed that the surcharge would allow them to bypass the rate case process and accelerate investments to replace aging pipelines. Evidence was provided that surcharges enabled accelerated investment. However, while general arguments about safety were made, there was no specific evidence provided, one way or another, that going through a normal rate case process had negatively affected safety in the past.²⁶²

A key feature of the STRIDE bill is that if the PSC approves the plan for pipeline replacement prepared by the utility as "reasonable and prudent," the utility's proposed recovery of funds via surcharges of up to \$2 per month per residential ratepayer would be automatically approved as well. Assuming a comparable amount per unit of gas sold would be collected from commercial customers, the annual surcharges could be as high as \$60 million per year. So far utilities have kept the surcharge generally below the limit, but there has nonetheless been a proposal to lift the cap to \$2.50 per month.²⁶³ The surcharge is set to zero when the investment is put into the rate base.

²⁶¹ Maryland General Assembly. Senate Bill SB 8, 2013 at <https://mgaleg.maryland.gov/mgaweb/Legislation/Details/sb0008?ys=2013RS&search=True>.

²⁶² Mary Dempsey and Alexander Núñez Position Statement of Baltimore Gas and Electric on House Bill 89 – Gas Companies – Rate Regulation – Infrastructure Replacement Surcharge, January 24, 2013

²⁶³ David Lapp, Office of People's Counsel, Testimony on House Bill 890, Natural Gas: Strategic Infrastructure Development and Enhancement Surcharge and Plans, before the Maryland House Committee on Economic Matters, February 18, 2021

The law had a number of other features that are important to the analysis in this report:

- The investments authorized were for existing infrastructure only; infrastructure for new customers was not included; the latter investments would continue to go through normal rate-case procedures.
- It incentivizes investments in pipe replacements over smaller repairs without due comparison of costs and safety impacts, even though the latter may be better on one or both counts. Utilities can recover the costs of repairs as operational expenses, but these are not included in the rate base and earn no profit, when the replaced pipe is short.
- Regulated gas companies were to prepare plans and submit them to the Commission, which was required to ensure that they were “reasonable and prudent” and that they were “designed to improve public safety or infrastructure reliability over the short term and long term.”
- At the time of the passage of the law, the PSC was neither required to consider nor prohibited from considering the compatibility of its approvals with the state’s climate goals and the implications that the legislation may have for stranded costs.
- The word “repair” does not appear in the legislation. The Commission was not prohibited from considering alternatives to the same safety and reliability purposes, should they be cheaper. The Commission was empowered to deny utilities’ project proposals if they were not “reasonable and prudent.” The criterion of “prudence” in regulatory review generally involves a cost test to protect consumers from excessive investments by utilities that could result in unneeded projects and added costs to consumers without commensurate benefit.
- Utilities were allowed to proceed with investments even without PSC approval, if that approval was not given within six months. But, if the PSC found the investments to be not reasonable or prudent, the utilities would be required to refund the amount.

In testimony, the Commission stated that it already had the authority to allow companies to recover investments through surcharges, though it did not oppose the 2013 STRIDE bill so long as it retained the authority to deny recovery if it deemed the investment to be not reasonable and prudent.²⁶⁴

The STRIDE bill gave the utilities greater latitude to impose surcharges to recover expenses, in place of regular rate-making procedures. Remarkably, though this extraordinary step was taken in the name of safety and reliability by reducing leaks of natural gas, no investment-specific metrics were put in place to ensure safety was actually improving in the

²⁶⁴ Maryland Public Service Commission, “PSC POSITION: Informational Comments; Technical Amendments Recommended,” Testimony on House Bill 89 before the Maryland House of Delegates January 24, 2013.

form of reduced rates of serious accidents. As the Office of People’s Counsel noted in its testimony opposing the bill, if the objective is to improve public safety and reliability by reducing leak rates, a baseline for leak rates and metrics for reductions in leak rates that result from the Plan and surcharge are needed as an incentive to control costs and prioritize repairs.

The bill also does not require demonstration of improved safety by the metric of reduction in the frequency of severe accidents or in their severity, as measured by the average number of serious injuries or fatalities per accident. Finally, the potential conflict with climate goals or the improvements in safety and health by accelerating phase out of natural gas in the residential sector were also not considered. As discussed below, both conflicts are much more serious than was recognized at the time the STRIDE bill was passed.

4.3.4 STRIDE Investments and Cost Recovery

As elsewhere in the United States, utilities prepared projects rapidly after the Maryland PSC approved investments for pipeline replacement. Six tranches of investments were proposed, each with a five year time horizon. Thus the investments began in 2014 and are proposed to continue until 2043. It is useful to consider some basics about the utilities before describing the scale of the investments, cost recovery, and the stranded cost risks associated with STRIDE.

4.3.4.1 Maryland’s Major Natural Gas Utilities

Table 4-2. shows the three major Maryland gas distribution utilities that are overseen by the Public Service Commission and the numbers of residential and commercial customers served by each.

Table 4-2: Major Maryland investor-owned natural gas utilities and number of customers. Source: PSC Gas enrollment report, December 2021.²⁶⁵

Maryland Utility	# Residential accounts	# Commercial Accounts	Total Gas Customers
BGE	651,589	44,081	695,670
Washington Gas	473,731	31,534	505,265
Columbia Gas	0	3,660	3,660
Total	1,125,320	79,275	1,204,595

Note: Smaller gas suppliers and publicly owned utilities are not included. They have a relatively small number of customers; the latter are not under the purview of the Maryland PSC. About half of Maryland’s residential electricity

²⁶⁵ Public Service Commission, Gas Choice Enrollment Report: All Utilities Where Gas Choice IS Available in Maryland – Quarter Ending December 2021, at <https://www.psc.state.md.us/gas/wp-content/uploads/sites/4/12-2021-Gas-Choice-Enrollment-Report.pdf>

customers have natural gas connections; about 85 percent of them use it as the main heating fuel, while the rest use it only for other purposes, such as cooking. The rest heat with electricity, fuel oil, and propane; a small number (less than one percent) use wood as their principal heating fuel.

Among the three major gas utilities, Baltimore Gas and Electric (BGE) has the largest number of gas customers and the most electricity customers in the state. It is owned by Exelon, a public utility holding company that also owns Pepco, an electric utility, and Delmarva Power, another electric utility. Exelon, via its regulated gas utility, serves about 58 percent of the gas customers; via its electric utilities, it serves about 80 percent of the electricity customers in Maryland.

4.3.4.2 STRIDE Investments

Two tranches of STRIDE investments have been approved by the Maryland PSC since the law went into effect on June 1, 2013; each was for investments over a five-year period. As shown in **Table 4-3**, work under the first tranche from 2014–2018 is complete. The second tranche, from 2019–2023, is being implemented. The other four tranches, which will extend the STRIDE investments to the year 2043, have not yet been applied for or approved.

Table 4-3: STRIDE Investments as approved (STRIDE I and II), and proposed (STRIDE III, IV, V, and VI). Source: OPC 2022.²⁶⁶

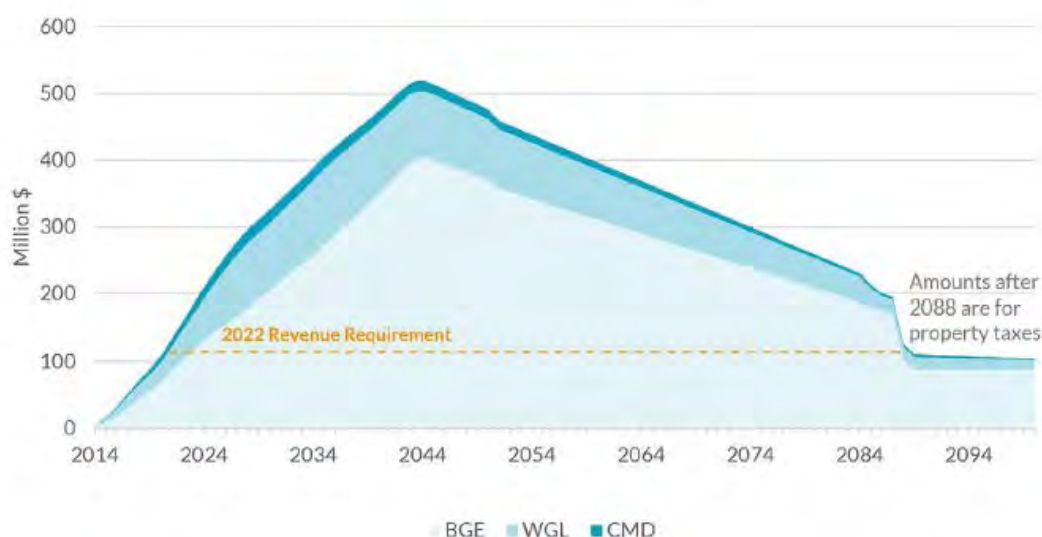
Stride Investment Plans, Largest Gas Utilities, Million \$			
	BGE	WGL	Columbia
Actual STRIDE I, 2014-2018	\$ 522.73	\$ 218.50	\$ 66.19
Actual/authorized, STRIDE II, 2019-2023	\$ 827.28	\$ 363.07	\$ 87.22
STRIDE III, 2024-2028	\$ 693.39	\$ 439.44	\$ 57.38
STRIDE IV, 2029-2033	\$ 803.83	\$ 194.82	\$ -
STRIDE V, 2034-2038	\$ 931.86	\$ 74.0	\$ -
STRIDE VI, 2039-2043	\$ 1,034.0	\$ -	\$ -
Total, per utility	\$ 4,813.58	\$ 1,302.19	\$ 210.79
Grand total, all three utilities	\$6,326.56		

The Office of People’s Counsel, which officially represents residential ratepayer interests in rate cases before the PSC (and which opposed the STRIDE legislation) has analyzed utility revenue requirements corresponding to these six five-year tranches of STRIDE investments.

²⁶⁶ Office of People’s Council. (October 2022.) Maryland Gas Utility Spending: Projections and Analysis. Office of People’s Council, State of Maryland, Table 1.1, p. 2.

The schedule of revenues for each utility and the combined total (by year), as estimated by the Office of People’s Counsel are shown in **Figure 4-4**.

Figure 4-4: Revenue requirements for the six STRIDE tranches as estimated by the Office of People’s Counsel for Baltimore Gas and Electric, Washington Gas, and Columbia Gas. Source: OPC 2022,²⁶⁷



It is clear that under the terms of the 2013 STRIDE law, the recovery of revenues, including profit, will continue for decades after the end of the investments; the recovered amounts will be roughly four times the investment amount. The recovery stretches out to the nearly the end of the 21st century. This is decades beyond Maryland’s 2022 Climate Solutions Now Act’s requirement of net zero greenhouse gas emissions by 2045. Some analysis is provided in the next section; suffice it to note here that four of the six tranches have not yet been approved. Investments under the two tranches of STRIDE that have been approved will continue into the 2030s for the two largest natural gas utilities (BGE and Washington Gas); as a result, ratepayers will be paying for those investments into the 2060s.

Table 4-4 shows the investments that are proposed for STRIDE tranches III to VI, by utility as well as the total for all three; it also shows the last date of investment in pipeline replacements, 2043, as currently proposed. Of the total STRIDE investments of about \$6.4 billion for all six tranches, two-thirds have yet to be authorized.

²⁶⁷ Ibid. p. 3

Table 4-4: Remaining proposed STRIDE investments 2024 onwards, not yet approved. Source: Based on OPC 2022,²⁶⁸ Figure 1b, omitting the 2022-2023 investments shown in that table.

(in millions of dollars)	BGE	WGL	Columbia
STRIDE III-VI	\$3,463.6	\$720.6	\$57.4
Total STRIDE III-VI, all three utilities	\$4,240.6		

4.3.5 STRIDE and Maryland's Climate Law

Stranded costs can occur in any commercial situation, but they are a very specific problem when it comes to investments by regulated utilities that are overseen and approved by utility commissions such as Maryland's Public Service Commission. In states like Maryland, wholesale electricity and natural gas transactions are not subject to state regulation of rates; but electricity and natural gas distribution companies are regulated; they purchase electricity and natural gas on wholesale regional markets and distribute it through electricity and gas distribution networks that they own. They get cost recovery on the purchase of natural gas on unregulated wholesale markets.

Historically, regulatory oversight was established over the distribution companies because they are granted monopolies over specified service territories—it would be far too expensive to have competing distribution networks. As part of the arrangement, they can recover their operating and maintenance costs, the costs of procuring energy, depreciation of their equipment, and a constitutionally guaranteed opportunity to earn a reasonable rate of return on the undepreciated amount. Rates are set so as to enable distribution utilities the opportunity to recover their costs and earn a profit.

The risk of stranded costs with natural gas or electric utilities can arise in several different ways. Generally, stranded assets emerge when a utility is systematically unable to recoup investments, including the rate of return, as well as operating costs, through revenues charged to customers on approved rate schedules. For instance, a significant part of electricity investments in costly nuclear power plants in areas where wholesale supply was deregulated became stranded because market prices were below the cost of nuclear electricity production. Coal plants were also at risk. One 1993 study calculated coal and

²⁶⁸ Ibid. Table 2.2, p. 11

nuclear stranded costs of electric utilities in the PJM grid (of which Maryland is a part) as \$11 billion, about equal to the book value of the utilities in question.²⁶⁹

4.4 Building Sector Decarbonization Implications

In the present instance, the general problem of stranded costs in the natural gas system comes from the need to eliminate fossil fuels from Maryland’s entire energy system as completely as possible by 2045—the date that the Climate Solutions Act has set for “net zero” emissions. The intermediate target is also very stringent: a 60 percent reduction in greenhouse gas emissions by 2031, relative to the baseline year of 2006.²⁷⁰

The 2022 climate legislation adopted the recommendation in the 2020 Annual Report of the Maryland Commission on Climate Change that the state adopt a target of net zero greenhouse gas emissions by 2045.²⁷¹ Given the importance of building energy consumption, the Maryland Department of Environment, the umbrella agency for the Maryland Commission on Climate Change, commissioned a Building Energy Transition Plan²⁷² that became a formal part of the Annual Report 2021 report of the Commission.²⁷³

The Building Energy Transition Plan provides a sound starting point to consider the question of stranded costs associated with natural gas, widely used as a heating fuel in Maryland. The next two fossil fuels for buildings, in order, are fuel oil and propane. Neither is regulated. The situation for those two fuels is therefore much like that of petroleum in general, including pipelines, gas stations, distribution companies, etc.; it is beyond the scope of this chapter. Fuel oil and propane are considered in the energy cost burden and policy chapters, since efficient electrification of households heated with these fuels can provide some of the greatest economic, emission reduction, and energy cost burden benefits.

²⁶⁹ Lester Baker, Eric Hirst, Estimating Potential Stranded Commitments for U.S. Investor-Owned Electric Utilities, ORNL/CON-406. Oak Ridge National Laboratory, Oak Ridge, Tennessee, January 1995, p. 8, at <https://www.osti.gov/servlets/purl/10122421>

²⁷⁰ Maryland General Assembly, Climate Solutions Now Act of 2022, Senate Bill 528, Effective Date June 1, 2022, Article 2-1201 and Article 2-2014.1, at <https://mgaleg.maryland.gov/2022RS/bills/sb/sb0528E.pdf>

²⁷¹ Maryland Commission on Climate Change, 2020 Annual Report, Maryland Department of the Environment, 2020, at <https://mde.maryland.gov/programs/air/ClimateChange/MCCC/Documents/MCCCAnnualReport2020.pdf>

²⁷² Maryland Commission on Climate Change, Transition Plan: A Roadmap for Decarbonizing the Residential and Commercial Energy Sectors in Maryland, Maryland Department of the Environment, 2021, at <https://mde.maryland.gov/programs/air/ClimateChange/MCCC/Commission/Building%20Energy%20Transition%20Plan%20-%20MCCC%20approved.pdf>

²⁷³ Maryland Commission on Climate Change, 2021 Annual Report, Maryland Department of the Environment, 2021, at <https://mde.maryland.gov/programs/air/ClimateChange/MCCC/Documents/2021%20Annual%20Report%20FINAL%20%282%29.pdf>

The most important assumption underlying the building transition plan is that a net zero energy sector by 2045 implies a 95 percent reduction of greenhouse gas emissions in the building sector. It initially considered three scenarios: “high electrification,” “electrification with fuel backup,” and “high decarbonized methane,” to achieve this goal, based on a study by the company E3.²⁷⁴

The initial draft of the E3 study concluded that the lowest total cost decarbonization scenario for buildings would be to use a gas supplement for heat pumps for use in times of the coldest weather in both the residential and commercial sectors. The main reason was that with electric heat pumps alone, heating demand on the coldest days would cause very high electric peak loads, necessitating high investments and costs in the electricity system.²⁷⁵

A number of problems with this conclusion were pointed out on review of the study by the Buildings Sub-Group of the Mitigation Working Group (MWG) of the Maryland Commission on Climate Change. For instance, it would be difficult to ensure that supplemental gas heating would be used only during the coldest hours. High gas costs would then deeply impact overall energy costs. A critical point was that with deep reductions in gas use, “delivery rates could increase more than 20-times the current rate for consumers left on the gas system, leading to significant equity concerns.”²⁷⁶

In light of this review, E3 constructed a fourth building decarbonization scenario, called the “MWG Policy” scenario. The final Building Energy Transition Plan describes its core as follows:²⁷⁷

- Ensure an equitable and just transition, especially for low-income households
- Construct new buildings to meet space and water heating demand without fossil fuels
- Replace almost all fossil fuel heaters with heat pumps in existing homes by 2045
- Implement a flexible Building Emissions Standard for commercial buildings.”

²⁷⁴ Tory Clark, Dan Aas, Charles Li, John de Villier, Michaela Levine, and Jared Landsman, Maryland Building Decarbonization Study: Final Report, Energy + Environmental Economics, October 2021, at https://mde.maryland.gov/programs/Air/ClimateChange/MCCC/Documents/MWG_Buildings%20Ad%20Hoc%20Group/E3%20Maryland%20Building%20Decarbonization%20Study%20-%20Final%20Report.pdf

²⁷⁵ Ibid., Slides 25 and 29.

²⁷⁶ Maryland Commission on Climate Change, Building Energy Transition Plan: A Roadmap for Decarbonizing the Residential and Commercial Energy Sectors in Maryland, Maryland Department of the Environment, 2021, p. 9, at <https://mde.maryland.gov/programs/air/ClimateChange/MCCC/Commission/Building%20Energy%20Transition%20Plan%20-%20MCCC%20approved.pdf>

²⁷⁷ Ibid., p. 9.

New residential and commercial buildings would be mandated to be all-electric starting in 2024. That is, new buildings would have no natural gas connections. In the present report, we use 2025 for this mandate, to allow about the same amount of time for the recommendation to be implemented as in the November 2021 Building Energy Transition report.

The major change from the earlier E3 study recommendation of electric heating with a gas supplement in both the residential and commercial sectors is that the MWG Policy scenario would have an essentially all-electric residential sector by 2045, with priority in the transition to low- and moderate-income retrofits, but there would be much more latitude for use of natural gas in the commercial sector. Overall natural gas use in all buildings, residential and commercial, would decline by only 75 percent by 2045. Since the residential sector would be all-electric, commercial sector natural gas use would decline only by about half, to about 36 trillion BTU. (See **Figure 4-1** above for historical use of natural gas in Maryland). Natural gas costs would rise several-fold, given increased distribution system costs. In addition, it is assumed that commercial sector buildings would choose to pay alternative compliance payments of \$100 per metric ton on more than 3 million tons of remaining CO₂-equivalent emissions.²⁷⁸ We note that if half of the commercial sector natural gas continues, it would not meet the target of 95 percent reduction in building sector greenhouse gas emissions by 2045 initially set forth in the E3 study.²⁷⁹

We are in general agreement with the recommendations of the MWG Policy scenario for the residential sector and note that they imply the dismantling of much of the natural gas pipeline infrastructure in residential areas. We have not analyzed buildings in the commercial sector and note that the Building Energy Transition report calls the assumptions about the commercial sector, including the alternative compliance payment “rough.” The assumption that commercial sector natural gas use would decline only by half while costs increased several-fold surely deserves more scrutiny. Would many businesses still consume so much natural gas when the cumulative tab would be over a billion dollars a year plus the cost of carbon payments? What about major retrofits? Or alternative heating systems? For instance,

²⁷⁸ Tory Clark, Dan Aas, Charles Li, John de Villier, Michaela Levine, and Jared Landsman, Maryland Building Decarbonization Study: Final Report, Energy + Environmental Economics, October 2021, Slides 49 and 60 at https://mde.maryland.gov/programs/Air/ClimateChange/MCCC/Documents/MWG_Buildings%20Ad%20Hoc%20Group/E3%20Maryland%20Building%20Decarbonization%20Study%20-%20Final%20Report.pdf

²⁷⁹ A 95 percent reduction in building sector emissions would leave well under 1 million metric tons of CO₂-equivalent emissions in 2045. But the revised E3 study recommendation would leave 3.1 million metric tons of CO₂-equivalent in 2045. See p. 46 of Tory Clark, Dan Aas, Charles Li, John de Villier, Michaela Levine, and Jared Landsman, Maryland Building Decarbonization Study: Final Report, Energy + Environmental Economics, October 2021, at https://mde.maryland.gov/programs/Air/ClimateChange/MCCC/Documents/MWG_Buildings%20Ad%20Hoc%20Group/E3%20Maryland%20Building%20Decarbonization%20Study%20-%20Final%20Report.pdf

there are major efforts to develop thermal storage technologies.²⁸⁰ Likewise, development of distributed hydrogen production could make it economical at the point of use, avoiding hydrogen transportation problems. In this light “several times” the current natural gas rate (that is, \$30, \$40 or more per MMBTU) is an unsuitable basis for long-term planning. Given the Climate Solutions Now Act, much more scrutiny is needed than a “rough” assumption for planning the future of heating in the commercial sector.²⁸¹ We have not retained this “rough” assumption in the analysis below as it appears economically speculative. Rather we have used deeper reductions in natural gas, with most of the remaining gas being used in the industrial sector in the analysis in **Section 4.5**.

Based on the E3 analysis of the MWG Policy scenario, the Building Energy Transition Report estimates that residential electricity prices would increase by about two cents per kilowatt-hour (in constant dollars), or about 15 percent. However, the E3 analysis did not take demand response into account. The Building Energy Transition report recommends that demand response (also called “demand management”) be included in electric system planning.²⁸² Given electrification of transportation, vehicle-to-grid technology is likely to play a large role in moderating peaks and increasing resilience. With the right incentives, demand response is likely to change the picture regarding peak electricity demand and electricity system investments considerably.

4.5 Natural Gas Distribution System Stranded Costs—Preliminary Considerations

The clear implications of the requirements of building sector decarbonization are that a complete or near complete elimination of natural gas emissions from the building sector by 2045 is necessary. It also means a steady decline of natural gas use between the effective date of the law, June 1, 2022 and 2045, especially since the intermediate goal for greenhouse gas emission reductions in the Climate Solutions Now Act for 2031 is a stringent 60 percent. Transportation sector emissions are likely to decline more slowly than those from either the buildings or electricity sector given that nearly the entire stock of vehicles uses fossil fuels and

²⁸⁰ Department of Energy, Thermal Energy Storage - Buildings, at <https://www.energy.gov/eere/buildings/thermal-energy-storage>, viewed on January 23, 2023

²⁸¹ For instance, \$40 per million Btu is equivalent to about \$5 per kilogram of hydrogen. This is roughly double the projected cost of distributed hydrogen production with electricity at 3 cents /kWh. Department of Energy, Hydrogen Production Cost from PEM Electrolysis - 2019, Table 1, at https://www.hydrogen.energy.gov/pdfs/19009_h2_production_cost_pem_electrolysis_2019.pdf

²⁸² Maryland Commission on Climate Change, Building Energy Transition Plan: A Roadmap for Decarbonizing the Residential and Commercial Energy Sectors in Maryland, Maryland Department of the Environment, 2021, p. 11 and p. 23, at <https://mde.maryland.gov/programs/air/ClimateChange/MCCC/Commission/Building%20Energy%20Transition%20Plan%20-%20MCCC%20approved.pdf>

the turnover rate of vehicles is slow. Moreover, unlike buildings, no economical retrofit technologies for converting existing fossil fuel vehicles is readily available. As a result, the reduction of natural gas use in buildings must be as close to 100 percent as possible.

Thus, an implication of the 2022 Climate Solutions Now Act of 2022 is that the natural gas distribution system serving buildings will likely become a stranded asset. *When* it becomes a stranded asset is a more complex question, but steeply rising costs are likely to accelerate that date. Most STRIDE investments and gas mains for supplying new infrastructure residential and commercial buildings have sixty-year periods over which they are depreciated.²⁸³ Revenue requirements are largely determined by recovery of investments, in addition to operating and maintenance requirements; profits are entirely related to investments that are in the rate base. The capital recovery and return on investment are fixed revenue requirements, while a large portion of the operating and maintenance cost is also fixed, and depends, among other factors, on the length of the pipelines in service.

Arguably, if natural gas supplied in the regulated arena—that is, mainly to buildings—is almost entirely phased out by 2045, the remaining book value of those assets could be considered stranded. However, much of the stranding will likely occur well before that time, since the cost of supplying a unit of gas will be, as a first approximation, inversely proportional to the amount of gas supplied unless entire sections of the distribution pipeline system are decommissioned and removed from the rate base as space heating and water heating are electrified.

For instance, the E3 report projected the cost of delivery of natural gas in 2045, when almost all heating is electrified, at \$140 per MMBTU.²⁸⁴ At a typical household use of 60 MMBTU per year of natural gas, the cost of delivery alone, at that rate, would be \$8,400 per year. Three percent of income is considered an affordable gas bill. Thus, for the delivery charge alone to be affordable, that household would have to have an income of \$280,000 per year. Add the

²⁸³ Mark D. Case, Rebuttal Testimony presented to the Maryland Public Service Commission on behalf of Baltimore Gas and Electric, Case Number 9331, November 6, 2013, p. 12, at [https://webapp.psc.state.md.us/newIntranet/Casenum/NewIndex3_VOpenFile.cfm?filepath=/Coldfusion/Casenum/9300-9399/9331/Item_16\9331-CaseRebuttalwATT\(Final\).pdf](https://webapp.psc.state.md.us/newIntranet/Casenum/NewIndex3_VOpenFile.cfm?filepath=/Coldfusion/Casenum/9300-9399/9331/Item_16\9331-CaseRebuttalwATT(Final).pdf)

²⁸⁴ The “unstructured” case in the E3 report is cited here. The report claims that requirements for revenues from ratepayers could be reduced report but admits that it has not examined the key question of who would fill that revenue gap. In any case, even the “structured” – reduced revenue case – has delivery costs estimated at \$100 per million Btu, which is also clearly unaffordable. Tory Clark, Dan Aas, Charles Li, John de Villier, Michaela Levine, and Jared Landsman, Maryland Building Decarbonization Study: Final Report, Energy + Environmental Economics, October 2021, pdf p. 32 at https://mde.maryland.gov/programs/Air/ClimateChange/MCCC/Documents/MWG_Buildings%20Ad%20Hoc%20Group/E3%20Maryland%20Building%20Decarbonization%20Study%20-%20Final%20Report.pdf

cost of the natural gas itself and using gas would be unaffordable for all but the very wealthiest Maryland households, who would likely have left the system long before that time.

The stranded cost question is therefore a dynamic one of considering an interaction between the Public Service Commission raising rates as consumption declines to match revenue requirements and customers investing in efficiency to reduce use and ultimately leaving the system altogether. Normally, conversion of a heating system would take place when an existing gas system needs to be replaced. Thus, the cost comparison between continuing on the gas system and electrifying with efficient heat pumps is a central issue in when the rest of the gas system becomes unviable. Put another way, the system becomes stranded at the point where *en masse* defections from gas to electricity occur due to high or very high gas prices. Continued STRIDE investments and investments in infrastructure to supply new buildings will only increase stranded costs.

The Buildings Subgroup of the Mitigation Working Group of the Maryland Commission on Climate Change compared highly efficient heat pumps with gas furnaces both in new housing and as retrofits for single family homes. The summary table from that report is reproduced in **Table 4-5** below.

Table 4-5: Comparison of natural gas plus central air conditioning costs with heat pump costs, including new construction and retrofits. Source: Buildings Subgroup Report 2020,²⁸⁵ Table 4, p. 11

	New Construction			Retrofit		
	Energy Cost	Fixed Cost	Total Cost	Energy Cost	Fixed Cost	Total Cost
ASHP Space Conditioner and ASHP Water Heater	\$4,850	\$6,850	\$11,700	\$11,175	\$10,550	\$21,725
Gas Space Heater, Gas Water Heater, and Electric AC	\$5,475	\$9,300	\$14,775	\$10,575	\$11,625	\$22,200
Difference	(\$625)	(\$2,450)	(\$3,075)	\$600	(\$1,075)	(\$475)

²⁸⁵ Buildings Subgroup, *Decarbonizing Buildings in Maryland*, Report to the Mitigation Working Group of the Maryland Commission on Climate Change, Maryland Department of Environment, September 2020.

By this assessment, from a residential heating point of view, the natural gas system already had marginal economics in 2020 both for new construction and for retrofits in single family homes, which constitute over 70 percent of the state's housing.²⁸⁶ Since that time, natural gas prices have risen due to national and global factors quite apart from the in-state STRIDE and other investments that have been authorized by the PSC.

Figure 4-5 shows the Henry Hub natural gas monthly average spot price history since the STRIDE law was passed in 2013. Prices have been rising since December 2021 (that is, before the start of the Russian invasion of Ukraine on February 24, 2022) from less than \$4 per MMBTU to more than \$7 per MMBTU in 2022. The lowest price in recent years was \$1.63 per MMBTU in May 2020 (impacted by the declining demand at the start of the COVID-19 pandemic). The costs of natural gas transportation through interstate pipelines to what is known as the "City Gate" where the regulated distribution service starts is in addition to the wholesale price of the gas itself. The price exclusive of distribution charges, taxes and other charges under the purview of the PSC is called the "commodity price," which is passed on to utilities' customers, subject to a later prudence review by the Commission. The commodity price cost of residential and general gas supply by Baltimore Gas and Electric, Maryland's largest gas utility, rose from a recent low of \$3.53 per MMBTU in September 2019 to \$11.02 per MMBTU in August 2022,²⁸⁷ implying a typical increase in residential gas bills of almost \$40 per month. In contrast, electricity prices in Maryland have declined for many years down to \$130.10 per megawatt-hour (MWh) in 2020.²⁸⁸ The recent increase to \$141/MWh in May 2022 is attributable to the increase in the wholesale price of natural gas, which is almost 40 percent of the state's electricity generation and a substantial part of its imported electricity.²⁸⁹

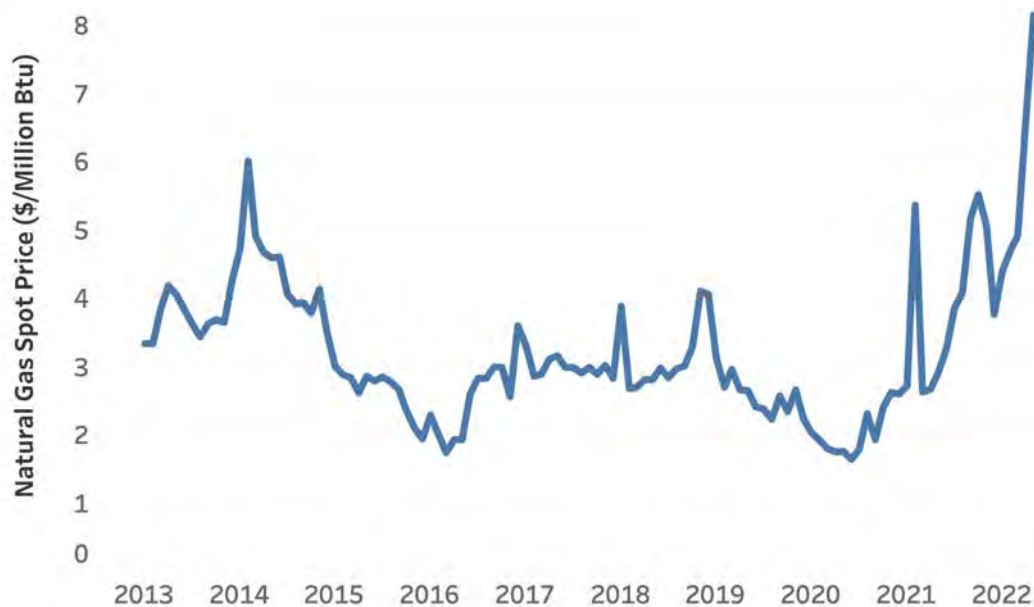
²⁸⁶ Maryland Housing Statistics at <https://www.infoplease.com/us/census/maryland/housing-statistics> viewed on August 15, 2022.

²⁸⁷ Baltimore Gas and Electric, Gas Commodity Prices: Schedule D – Residential and Schedule C – General Service, at https://www.bge.com/MyAccount/MyBillUsage/Documents/Gas/GasCommodity_SchedD%20and%20SchedC.pdf viewed on August 19, 2022.

²⁸⁸ Average residential electricity prices have declined since 2013 to 2020. They declined almost every year. Energy Information Administration State Electricity Profiles, Profile for Maryland at <https://www.eia.gov/electricity/state/maryland/> viewed on August 19, 2022.

²⁸⁹ EIA State Electricity Profile for Maryland, *ibid.*, EIA Monthly electricity report for May 2022, release date July 26, 2022 at https://www.eia.gov/electricity/monthly/current_month/july2022.pdf in addition to Henry Hub price data cited in the next footnote.

Figure 4-5: Henry Hub natural gas spot prices (wholesale), monthly averages. Source: EIA 2022²⁹⁰



In brief, global, national, as well as in-state factors have set the stage for the distribution assets of Maryland’s regulated natural gas companies to become stranded assets in the context of the state’s ambitious Climate Solutions Now Act.

4.5.1 Basis of Stranded Cost Calculations

The E3 report prepared for the Maryland Department of the Environment, which hosts the Maryland Commission on Climate Change, estimated the 2021 natural gas system delivery cost (that is, apart from the commodity price, as discussed above) to be about \$1.05 billion.²⁹¹ Revenue requirements will increase as a result of already authorized STRIDE investments and the four additional STRIDE tranches if they are authorized, as they may well be under current law. We consider the impact of recovery of \$1.05 billion per year plus STRIDE investment (in

²⁹⁰ Energy Information Administration, Henry Hub Natural Gas Spot Price, at <https://www.eia.gov/dnav/ng/hist/rngwhhdm.ht> viewed on August 19, 2022.

²⁹¹ Tory Clark, Dan Aas, Charles Li, John de Villier, Michaela Levine, and Jared Landsman, Maryland Building Decarbonization Study: Final Report, Energy + Environmental Economics, October 2021, read from the chart on p. 112, at https://mde.maryland.gov/programs/Air/ClimateChange/MCCC/Documents/MWG_Buildings%20Ad%20Hoc%20Group/E3%20Maryland%20Building%20Decarbonization%20Study%20-%20Final%20Report.pdf

round numbers) as natural gas use in the regulated sector declines steadily reaching a 95 percent reduction by 2045. This reduction in use is assumed to be due to electrification of natural gas uses or to use of hydrogen produced on site and/or transported by dedicated pipelines.

The framework used is to assume that the main declines will occur because homes and businesses using natural gas for space and water heating will depart the system at an accelerating pace and rates increase to keep revenues constant as natural gas use declines. We will assume, for simplicity, that the commodity price of natural gas—production plus transport to the “city gate”—will stay constant at \$6 per MMBTU, the approximate level in early 2022 before the Russia-Ukraine war. We also do a sensitivity analysis to demonstrate that the commodity price assumption is not central to the stranded cost calculation. We also examine how much earlier than 2045 the natural gas system might be considered to be stranded. **Table 4-6** shows the approximate level of reductions in various sectors that would be required to achieve the 2031 and 2045 goals of the Climate Solutions Now Act.

Table 4-6: Conceptual levels of reduction in sector greenhouse gas emission reductions needed to achieve Climate Solutions Now Act targets (rounded).Source for 2006 greenhouse gas inventory Maryland Department of Environment 2006²⁹²

	2006	2031		2045	Comments
	Million mt CO ₂ e	Million mt CO ₂ e	% reduction	Million mt CO ₂ e	% reduction
Electric power	42.5	12.8	70%	0	100%
Res., Comm. Industrial, natural gas, propane	9.21	5.5	40%	0.9	90%
Residential, Comm. Industrial, other fossil fuels	7.69	3.5	55%	0	100%
Transportation, on road	29.6	11.8	60%	1.5	95%
Transportation, other	5.9	4.7	20%	1.2	80%
Fossil Fuel industry	1.3	0.5	60%	0.06	95%
Emissions and % reduction	96.2	38.8	59.7%	3.7	95%

Note 1: Fuel oil and propane have been higher in cost than natural gas; the assumption here is that those direct end uses would be electrified first. However, that assumption may not hold as petroleum use declines and the cost of natural gas rises due to revenue recovery requirements from smaller volumes. Most or all of the remaining natural gas would likely be in the industrial sector.

Note 2: The 2031 60 percent goal for on-road transportation emission reductions requires roughly 70 percent of new vehicle sales be EVs by that date. The 20 percent is a derived number to achieve ~50 percent transportation reductions by 2031.

²⁹² Maryland Department of Environment, Greenhouse Gas Inventory, 2006, at https://mde.maryland.gov/programs/air/ClimateChange/Documents/VIMAL/MD_2006_GHG_Inventory_updated%202022-09-24.xlsx

The basic assumption in a calculation of stranded costs of natural gas infrastructure is that the volume of energy sold through that infrastructure will also decline. As discussed in above, the “highly decarbonized methane” scenario in the E3 study envisions such an option though most of the gas in its high decarbonized methane scenario would be synthetic methane.²⁹³ This scenario had the highest costs (with methane costs in the \$30 to \$70 per MMBTU range); these costs were in addition to the delivery costs of methane, which would be on the order of \$15 to \$20 per MMBTU.²⁹⁴ This would make for a total cost of \$45 to \$90 per MMBTU of delivered gas. This means that a typical residential consumption of about 70 MMBTU per year would result in an annual fuel cost of \$3,000 to \$5,000 (rounded). Mass migration away from “highly decarbonized gas” would occur long before that cost was reached, leaving fewer and fewer consumers to pay for the gas infrastructure. Renters with gas heating would likely be the most adversely affected, with low-income renters suffering the worst—unless massive amounts of energy bill payment assistance are provided. In that case, the bills of other ratepayers would go up even more; in the alternative, taxpayers would bear the burden. Neither is an attractive or even realistic option; see **Chapter 5**.

The E3 study acknowledges that the “highly decarbonized gas” scenario is also the most technologically uncertain of the three it considered (electrification and electrification with a fuel supplement being the other two). It would require large amounts of biomass inputs, some of which would have to come from outside Maryland; in the alternative, more synthetic gas would have to be made by CO₂ capture and hydrogen produced by renewable energy, a higher cost option.²⁹⁵

Finally, the E3 study also did not consider the health impacts of continued use of methane as a fuel, whether this related to outdoor or indoor air pollution. Further, adding hydrogen to the methane mix may also increase NO_x pollution due to the higher flame temperature; the much higher flame speed of hydrogen also requires specialized equipment when the hydrogen fraction in the fuel is high.²⁹⁶

²⁹³ The E3 study has an “optimistic case” and a “conservative” case for decarbonized gas supply. Even in the “optimistic case, about 85 percent of the supply is synthetic methane, the most costly element of supply. Tory Clark, Dan Aas, Charles Li, John de Villier, Michaela Levine, and Jared Landsman, Maryland Building Decarbonization Study: Final Report, Energy + Environmental Economics, October 2021, p. 13 at https://mde.maryland.gov/programs/Air/ClimateChange/MCCC/Documents/MWG_Buildings%20Ad%20Hoc%20Group/E3%20Maryland%20Building%20Decarbonization%20Study%20-%20Final%20Report.pdf

²⁹⁴ Ibid. pp. 114-115

²⁹⁵ Ibid. pp. 13-14.

²⁹⁶ General Electric, Hydrogen for Power Generation: Experience, Requirements, and Implications for Use in Gas Turbines, March 2022, pp. 13-14, at https://www.ge.com/content/dam/gepower-new/global/en_US/downloads/gas-new-site/future-of-energy/hydrogen-for-power-gen-gea34805.pdf

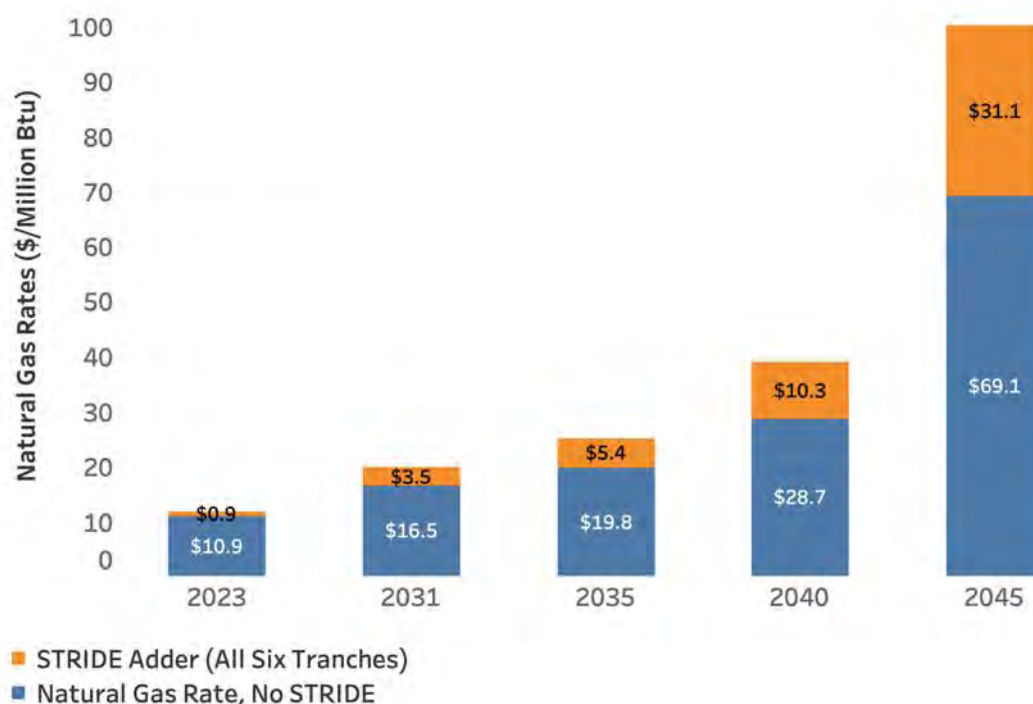
In sum, the use of existing natural gas infrastructure for mixtures of methane and hydrogen to supply building is unrealistic to the point of being infeasible from the point of view of cost, environmental justice, health, or sheer practicality, since it is highly likely that most customers would abandon the option of energy delivery for heating and cooking uses via pipeline long before a substantial fraction of the required energy could be supplied in that fashion, contrary to the assumption in the E3 study that gas energy use via the pipeline infrastructure would decline only 19 percent relative to 2021.²⁹⁷

The practical implication for this study is that all-electric new buildings and all electric retrofits are most likely to become the norm and are compatible with the greenhouse gas targets of the Climate Solutions Now Act. For simplicity, we examine the impact on fuel rates and heating bills of those who may not have the option to convert to efficient electric heating; the most likely impacted households would be renters and, among them, low-income renters would likely be disproportionately represented. This highlights the need to give priority to electrification of heating of low- and moderate-income households.

Figure 4-6 shows the evolution of natural gas rates under the assumptions of reduction of natural gas use shown in Table 4-3 above (40 percent by 2031 and 90 percent by 2045).

²⁹⁷ Tory Clark, Dan Aas, Charles Li, John de Villier, Michaela Levine, and Jared Landsman, Maryland Building Decarbonization Study: Final Report, Energy + Environmental Economics, October 2021, p. 12, at https://mde.maryland.gov/programs/Air/ClimateChange/MCCC/Documents/MWG_Buildings%20Ad%20Hoc%20Group/E3%20Maryland%20Building%20Decarbonization%20Study%20-%20Final%20Report.pdf

Figure 4-6: Potential evolution of natural gas rates for 40 percent reduction of natural gas end-use by 2031 and 90 percent by 2045.



Note: The commodity price of natural gas is assumed to stay constant at \$6/MMBTU. This is considerably lower than the price in 2022 (average price from January to August 2022 was \$7.70; in August 2022 it was \$10.10).²⁹⁸

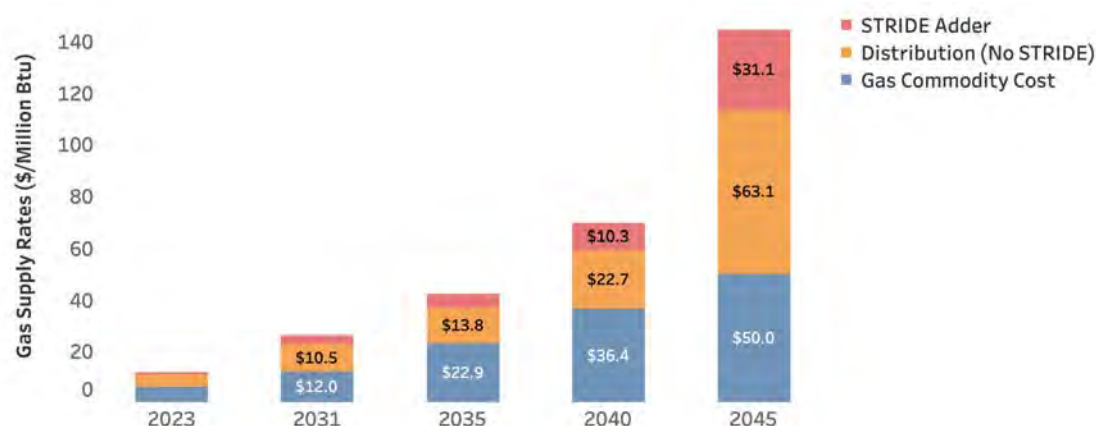
A rapidly declining portion of the total rate would be represented by the natural gas itself (not separately shown in **Figure 4-6**). In 2035, that fraction would be 25 percent; in 2045, it would be only six percent. In other words, from the 2030s and into the 2040s, the delivery cost would dominate the rate; within the distribution portion the fraction attributable to STRIDE would increase from about 10 percent in the early to mid-2020s to over 30 percent in 2045.

The above is a rather optimistic construct of the use of the natural gas infrastructure since it assumes that natural gas would continue to be used and that it would be available at low cost. The much more likely case in the context of the Climate Solutions Now Act is that the gas would be synthetic “decarbonized gas” produced at high cost; this is the assumption, for

²⁹⁸ Baltimore Gas and Electric, Gas Commodity Prices: Schedule D – Residential and Schedule C – General Service, at https://www.bge.com/MyAccount/MyBillUsage/Documents/Gas/GasCommodity_SchedD%20and%20SchedC.pdf

instance, in more than one scenario in the E3 study. Heavy industries (like cement production) and non-road transportation, notably air transportation, are difficult sectors to decarbonize; in the latter case no clear path is even available at present, though electrification, hydrogen, and biofuels are being explored. Given the cost and complexity of carbon capture and sequestration, these difficult sectors are likely to be the preferred ones to apply that approach for achieving net zero by 2045. As a result the likely options for buildings are (i) complete disconnection from gas, or (ii) use of verifiably decarbonized synthetic gas. In the former case, the entire natural gas distribution system will become a stranded cost by 2045 at the latest. In the latter case the high cost of commodity gas will add to the rates shown in **Figure 4-3** above. **Figure 4-7** shows the result of assuming a gradual increase in the cost of commodity gas from the \$6/MMBTU assumed in **Figure 4-6** (about \$5 lower than August 2022 cost) to \$12/MMBTU in 2031, linearly increasing to \$50/MMBTU by 2045. The latter cost is the middle of the range of “highly decarbonized gas” cost estimates in the E3 study.²⁹⁹

Figure 4-7: Estimated rates for gas supply with synthetic decarbonized gas supplying 10 percent of the requirements in 2045.



Note: The commodity price of natural gas is assumed to stay constant at \$6/MMBTU. This is considerably lower than the price in 2022 (average price from January to August 2022 was \$7.70; in August 2022 it was \$10.10).³⁰⁰

²⁹⁹ Tory Clark, Dan Aas, Charles Li, John de Villier, Michaela Levine, and Jared Landsman, Maryland Building Decarbonization Study: Final Report, Energy + Environmental Economics, October 2021, p. 114, at https://mde.maryland.gov/programs/Air/ClimateChange/MCCC/Documents/MWG_Buildings%20Ad%20Hoc%20Group/E3%20Maryland%20Building%20Decarbonization%20Study%20-%20Final%20Report.pdf

³⁰⁰ Baltimore Gas and Electric, Gas Commodity Prices: Schedule D – Residential and Schedule C – General Service, at https://www.bge.com/MyAccount/MyBillUsage/Documents/Gas/GasCommodity_SchedD%20and%20SchedC.pdf

This synthetic gas scenario can also be used to examine the option of electric heating with a gas supplement of 10 percent of the total heating requirement. With total costs rising to \$140/MMBTU by 2045, the cost of that 10 percent would be about \$1,000 (rounded) assuming a heating end-use requirement of 70 MMBTU, a typical amount used currently; incidentally it is also a typical total annual gas bill. Thus, a small fraction of the heating energy requirement in 2045 would essentially double the cost of heating relative to the present. From the point of view of customers who have a choice, complete electrification would be much more economical, whether in new construction or at the time of replacing an existing gas system. This is because the heat pump costs are approximately on par with natural gas furnace heating plus central air conditioners at present (see **Table 4-5** above). Even with the most expensive—and most efficient—option, geothermal heat pumps, would be very attractive. This is because the added cost of the geothermal heat pump, attributable to the geothermal well, which is on the order of \$10,000, would be generally lower than the cost of the supplemental gas.³⁰¹ In addition, geothermal heating and cooling would significantly reduce the cost of electricity and both the summer and winter peak loads on the system (relative to air-to-air heat pumps), providing benefits both to the household and the electric grid.

If the supplemental decarbonized gas approach is adopted as policy it would mean that only low- and moderate-income households who are unable to transition to full electrification would remain in the system, with harmful consequences for energy cost burdens and health. For instance, an increase in gas bills by \$1,000 per year would increase the energy cost burden of a family of three at 50 percent of the federal poverty level by more than eight percent, making even *the increment in cost unaffordable all by itself* at that income level or below.

The Maryland Office of People’s Council published a more detailed study in November 2022 examining the impact of declining natural gas use on rates. The results are broadly similar to those discussed above, but differ in detail because the scenarios evaluated were somewhat different.³⁰²

³⁰¹ Geothermal heat pump costs average about \$25,000 (before rebates and incentives): Home Remodeling: “How Much Does a Geothermal Heat Pump Cost to Install?” March 19, 2021 at <https://homeguide.com/costs/geothermal-heat-pump-cost>. The installed cost of highly efficient air-to-air heat pumps are in the \$12,000 to \$18,000 range: Home Remodeling Cost Guide, “Top 10 Heat Pumps for 2022: Costs, Unit Pros & Cons,” February 21, 2022, at <https://www.remodelingcosts.org/top-10-heat-pumps-costs/>. Assuming a 25-year loan at 5%, and a \$10,000 added cost, the added annual cost would be about \$700 (rounded). The cost with a shorter loan term of 15 years would be about \$960 per year. Taking the 30 percent federal tax incentive into account, the annual added cost for a geothermal heat pump would be about \$500 per year (25-year loan) or about \$670 per year (15-year loan).

³⁰² Synapse Energy Economics, Climate Policy for Maryland’s Gas Utilities: Financial Implications, report prepared for the Maryland Office of People’s Counsel, November 2022. For BGE, the largest gas utility, the report estimated the rates in 2035 to be between \$29 per MMBTUmillion and \$39 per MMBTUmillion, while the range estimated above is \$25 to \$42 per MMBTU. Similarly the Office of People’s Counsel estimated the rates in 2050 to be

4.5.2 Avoiding Stranded Costs³⁰³

An essential element of avoiding stranded costs is to stop new investments in natural gas infrastructure and to stop open-ended STRIDE investments that are put into the rate base. This will minimize stranded costs but will not altogether avoid them since investments in recent years have recovery periods considerably beyond 2045. Alternative uses of the infrastructure or the infrastructure underground space could help mitigate much or most of the problem, provided those uses are compatible with the Climate Solutions Now Act, affordability, and equity.

The E3 study, discussed above, proposed two such approaches. One of them, replacing natural gas mainly with synthetic gas is technologically speculative and economically unaffordable. The other would be to maintain the pipeline infrastructure for synthetic gas and biogas as a supplemental fuel. Among other things, this would mean that the entire cost of the infrastructure would be imposed on a small fraction of the gas use, apart from all other considerations such as indoor air pollution. Yet, the study acknowledges that the costs of delivery of gas alone would rocket from well under \$10 per MMBTU to between \$90 and \$140 per MMBTU by 2045, due to the much smaller amount of gas flowing through the pipes. It admits that its analysis “does not address the question of how utilities would reduce the revenue requirement or how it would bear the cost gap between reduced revenue requirement and unavoidable costs of the remaining gas system.”³⁰⁴

The best approach is to create an orderly transition enabling utilities to shut down the natural gas distribution infrastructure, neighborhood by neighborhood, by focusing energy transition efforts, especially electrification, along those lines. Priority could, and should, be given to those areas with older pipes considered vulnerable or areas identified as having safety issues. Stranded costs could be avoided in some or many cases by using the underground right of way to replace the natural gas pipes with geothermal pipes carrying heating and cooling energy from shallow geothermal closed-loop wells to individual buildings equipped with suitable heat pumps.

between \$101 per MMBTUmillion and \$146 per MMBTUmillion. The estimates in this report for 2045 are between \$100 and \$140 per MMBTUmillion; (all estimates round). The Office of People’s Counsel rates estimated for the smaller gas utilities to be somewhat lower than for BGE.

³⁰³ This section covers only natural gas distribution infrastructure as it relates to supply to buildings for space and water heating, cooking, and clothes drying. It does not cover industrial uses of natural gas, which requires separate study.

³⁰⁴ Tory Clark, Dan Aas, Charles Li, John de Villier, Michaela Levine, and Jared Landsman, Maryland Building Decarbonization Study: Final Report, Energy + Environmental Economics, October 2021, p. 32, at https://mde.maryland.gov/programs/Air/ClimateChange/MCCC/Documents/MWG_Buildings%20Ad%20Hoc%20Group/E3%20Maryland%20Building%20Decarbonization%20Study%20-%20Final%20Report.pdf

Gas utilities in some parts of the United States, among others, are considering replacing gas pipeline distribution infrastructure with networked geothermal heating and cooling pipe infrastructure, which is distributed by nature. For example, Eversource is a company that supplies electricity, natural gas, and water to parts of Massachusetts, Connecticut, and New Hampshire. It has embarked on a program of networked geothermal wells to supply heat, starting with a pilot project that “could lead to expansion of the technology in the future.”³⁰⁵ An example of a project that has been completed is the one built at Colorado Mesa University. The project cost was \$8.2 million; the annual energy bill savings are \$1 million. Demonstration projects are being planned or built in several states, facilitated by suitable legislation.³⁰⁶ While the pipelines themselves would be removed, they would be replaced by similar pipe infrastructure for carrying glycol, the commonly used fluid for geothermal wells. It is as yet unclear how widely this approach may be applicable and what incentives would be needed for broad adoption.

Using distributed geothermal wells and heat pumps to electrify heating in neighborhoods depends on the density of space heating needs; it can consist of a mixture of residential and commercial structures. Below a certain density, individual wells and heat pumps are suitable; above a certain maximum, supplemental wells not on the same street may be required to meet all the requirements. Obviously, building envelope improvements could also help fill some or all of the gap in such cases. This approach would be particularly suitable in Baltimore City, which is a big part of Baltimore Gas and Electric territory where most of the STRIDE investments are taking place.³⁰⁷

4.6 Brief Overview of the Gas Pipeline Leak, Safety, and STRIDE

STRIDE investments, which involve pipeline replacements, have generally been justified in Maryland, as elsewhere, in the name of safety. However, according to the PSC interpretation in a 2013 case involving Baltimore Gas & Electric, the 2013 law allows investments that are far

³⁰⁵ “Networked Geothermal Energy, Eversource, at <https://www.eversource.com/content/ema-c/residential/about/sustainability/renewable-generation/geothermal> viewed on November 21, 2022

³⁰⁶ Energy We Can’t Afford Coalition, How Networked Geothermal Can Help Get Minnesota Off natural gas, Fresh Energy Webinar video, September 21, 2022, at 26 minutes, 21 seconds, slides by www.heet.org at <https://www.youtube.com/watch?v=Qt2d0FILzZg> In July 2022, New York passed a law that would “promote the development of thermal energy networks throughout the state and to provide jobs to transitioning utility workers who have lost or are at risk of losing their employment.” The term “thermal energy networks” includes geothermal well networks. “New York Approves Landmark Thermal Network Legislation,” Geothermal Rising, July 6, 2022, at <https://geothermal.org/our-impact/blog/new-york-approves-landmark-thermal-network-legislation>

³⁰⁷ Burohappold Engineering, G&E Micro District Feasibility Study, heet, 2021, at <https://heet.org/wp-content/uploads/2019/11/HEET-BH-GeoMicroDistrict-Final-Report-v2.pdf>

broadly so long as a safety improvement is claimed, even without metrics for those investments. Specifically, BGE proposed not only to replace pipes that were leaking under the terms of STRIDE, but also to replace pipes that might be “leak-prone.”³⁰⁸ Thus the metrics of actually reducing leaks, reducing greenhouse gas emissions, and improving safety in the short-term that may justify accelerated replacement and recovery with surcharges, was conflated with a judgment of the company that essentially lacks the clear metric of reducing leaks, not to speak of the metric of reducing serious accidents.

We have already cited (above in this chapter) a generally similar case in 2011, that is, before the STRIDE law was passed, in which Washington Gas Light had applied to the PSC to replace pipes and apply a surcharge as part of the recovery of the investment. The PSC affirmed, in agreement with the company, “that safe and reliable infrastructure is the highest priority” but did not approve the surcharge for “the recovery of future pipe replacement expenses”—the economic essence of the STRIDE law and of the PSC’s approval of the BGE 2013 application under that law. The basic argument in the 2011 rejection of the surcharge was that both normal and safety-related accelerated pipeline replacement could occur “using traditional ratemaking procedures without compromising its [the utility’s] ability to earn an appropriate return.”³⁰⁹

Climate and stranded costs were not a central consideration in 2011 or in 2013, the year the STRIDE law was passed, so far as natural gas use was concerned. The passage of the Climate Solutions Now Act in 2022 has dramatically changed that. Moreover, a 2021 law requires the PSC to take the climate change impacts of its actions into account using the latest science published by the Intergovernmental Panel on Climate Change.³¹⁰ The Climate Solutions Now Act greenhouse gas targets for 2031 and 2045 are broadly consonant with that science. The federal Inflation Reduction Act is also likely to have a major impact in spurring electrification of the economy, due to its many provisions spurring the energy transition. These include a

³⁰⁸ Testimony of BGE witness Biagiotti, as quoted in the Commission’s Order in Case 9331, p. 21. Maryland Public Service Commission, Order No. 86147 in the Matter of the Application of the Baltimore Gas and Electric Company for Approval of a Gas System Infrastructure Development and Enhancement Plan and Accompanying Cost Recovery Mechanism: Before the Public Service Commission, Base No. 9331, January 19, 2014, at https://webapp.psc.state.md.us/newIntranet/Casenum/NewIndex3_VOpenFile.cfm?FilePath=//Coldfusion/Case num/9300-9399/9331/37.pdf

³⁰⁹ In the matter of the Application of the Washington Gas Light Company for Authority to Increase its Existing Rates and Charges and to Revise its Terms and Conditions for Gas Service, Maryland Public Service Commission Order 84475, Rate Case 9267, November 14, 2011, at https://webapp.psc.state.md.us/newIntranet/Casenum/NewIndex3_VOpenFile.cfm?FilePath=//Coldfusion/Case num/9200-9299/9267/98.pdf

³¹⁰ Maryland Code, Public Utilities, § 2-113, Duty of Commission to supervise and regulate public service companies, Effective: October 1, 2021

ten-year extension of the investment tax credit for solar energy and storage, weatherization investments, and rebates for high efficiency electric homes.³¹¹

As demonstrated in the analysis in this chapter, continued investments in STRIDE, and by implication, new investments that increase the rate base of Maryland’s gas utilities will accelerate the stranding of Maryland’s gas pipeline infrastructure, significantly increase costs, and also exacerbate economic, environmental, and health inequities in the state’s energy system. Thus, it is essential to find ways to minimize exposure of the state’s ratepayers (and potentially taxpayers) to stranded costs while improving safety and meeting the goals of the Climate Solutions Now Act. These matters are discussed in **Chapter 5** on policy. It is nonetheless important to look at national and state safety data in light of the rush of investments in pipeline replacements and consequent increases in profits of regulated utilities that followed the report of the National Technical Safety Board on the 2010 San Bruno, California accident and subsequent actions by the federal Department of Transportation (discussed above).

4.6.1. National Serious Accident Data

Table 4-7 shows the number of serious natural gas accidents in the United States between 2005 and 2021 (inclusive), sorted by the causes of the accidents. Accidents are classified as “serious” whenever there is a serious injury or fatality involved.

³¹¹ Sylvia Chi, IRA: Our Analysis of the Inflation Reduction Act, Just Solution Collective, 2022, at https://assets-global.website-files.com/5fd7d64c5a8c62dc083d7a25/63232854dd4d104128f01b8c_JSC%20-%20Analysis%20of%20the%20Inflation%20Reduction%20Act%20-r3.pdf

Table 4-7: National data on serious natural gas accidents. Source: Data from PHMSA 2022³¹² sorted for this report.

Serious Accidents 2005-2021, National Data			
Equipment failure	10	2.3%	
Corrosion	16	3.7%	possibly aging and pipe material related
Natural force damage	24	5.6%	
Material failure of pipe or weld	41	9.5%	
All other causes	54	12.5%	
Incorrect operation	64	14.8%	
Excavation damage	108	25.0%	
Other outside force damage	115	26.6%	69% due to vehicular damage
Total	432	100.0%	

Corrosion, which can be attributed to age and type of pipe, was responsible for only 3.7 percent of all serious accidents, while incorrect operation, excavation damage, vehicular damage were responsible for a significant majority of accidents. Material failures accounted for 9.5 percent of the total. For example, in the 2010 San Bruno accident, discussed above, the problem with the weld that caused the accident dated to the time of installation and should have been noticed then; age was thus not the primary causative factor in that accident. Further, the frequency of serious accidents in the eight-year period 2014–2021 (inclusive) was only marginally better than in the prior eight year period 2006–2013 (inclusive), indicating that the investments in pipeline replacement that have been made in the wake of the accident have not materially improved safety.³¹³ **Table 4-8** shows Maryland data, by year and cause of accident in the 2005-2021 period.

³¹² Pipeline and Hazardous Materials Safety Administration, U.S. Department of Transportation at <https://portal.phmsa.dot.gov/analytics/saw.dll?Go>

³¹³ The comparison periods were chosen because, as in the case of Maryland, 2014 would be the first year in which widespread investments would have been made pursuant to federal and state legislation and regulatory actions by state regulatory bodies.

Table 4-8: Serious natural gas system accidents in Maryland, 2002-2021.

Year	Date	City	County	System Part	Cause	SubCause	# of Fatalities	# of Injuries
2007	7/14/07	Frederick	Frederick	Pressure Limiting and Regulating Facility	Other Outside Force Damage	Vehicle Not Engaged in Excavation	0	1
2008	4/29/08	Baltimore	Baltimore City	Service Line	Corrosion	External	0	1
2009	5/7/09	District Heights	Prince George's	Main	All Other Causes	Miscellaneous	0	2
2013	8/2/13	Beltsville	Prince George's	Other	All Other Causes	Unknown	0	1
2014	2/19/14	Baltimore		Other	All Other Causes	Unknown	1	2
2016	8/11/16	Silver Spring	Montgomery	Other	All Other Causes	Unknown	7	33
2018	6/9/18	Baltimore	Baltimore City Is Not Within Baltimore County	Main	Material Failure of Pipe or Weld	Other Pipe/Weld/Joint Failure	0	1
2021	5/14/21	Pikesville	Baltimore County	Main	Incorrect Operation	Other Incorrect Operation	1	1

Source: Data extracted from PHMSA 2022³¹⁴ sorted for this report.

All of the fatalities in the Maryland natural gas system and the vast majority of injuries in the 2005-2021 period occurred after the passage of the STRIDE law. The vast majority of both fatalities and injuries were due to a single 2016 accident at the Flower Branch Apartments in Silver Spring Maryland, which did not involve the gas distribution system. The NTSB concluded that the cause was “the failure of an indoor mercury service regulator with an unconnected vent line...”³¹⁵ inside the building. The NTSB made a number of

³¹⁴ Pipeline and Hazardous Materials Safety Administration, U.S. Department of Transportation at <https://portal.phmsa.dot.gov/analytics/saw.dll?Go>

³¹⁵ National Transportation Safety Board Press Release, “Failed Gas Regulator, Unconnected Vent Line Led to Maryland Apartment Building Explosion,” April 23, 2019 at <https://www.nts.gov/news/press-releases/Pages/nr20190423.aspx>

recommendations, some of which involved utility actions and costs.³¹⁶ However, no STRIDE type of program for accelerated recovery of costs outside of rate cases was put in place.

The 2014 fatality was due to falling debris caused by a gas explosion inside a building (in Baltimore City); the building was destroyed.³¹⁷ The ninth and latest fatality in the 2005-2021 period occurred in 2021; a worker was killed in an excavation accident; as is clear from **Table 4-8**, this is the most frequent kind of serious accident related to natural gas.

In addition to the above list of serious accidents in Maryland, two other explosions that caused serious injuries apparently caused by natural gas occurred in March 2022³¹⁸ and November 2022.³¹⁹ Both were in Montgomery County, Maryland's most populous, were inside buildings and caused significant damage. While official National Transportation Safety Board reports are not yet available, neither explosion appears to have involved pipelines.

So far as Maryland is concerned all the fatalities in serious natural gas explosions in the 2005-2021 period occurred after the passage of the STRIDE law. Only one serious injury in the entire period was due to an accident where the primary cause is listed as pipe corrosion. Moreover, as noted, STRIDE does not require a prioritization for detection of actual unsafe conditions and corroded pipes. The broad assumption is that by replacement of aging pipes or pipes prone to corrosion and leaks, safety would be improved—over a time period that is expected to take decades since utilities are planning pipeline investments well into the 2040s.

This is not to say that leaks should not be repaired or safety be given anything less than the highest priority. If safety is the highest priority and its improvement is to be accelerated, the historical record in Maryland and nationally shows that investments and expenditures would have been better prioritized in other areas, such as natural gas infrastructure in buildings, worker safety, and worker training. Given the scale of injuries and fatalities related to apartment building explosions, these should evidently be a high priority both for safety and electrification with disconnection of natural gas. We are not aware of any environmental and health justice investigations that have been done in relation to the serious accidents in Maryland rental properties in recent years and natural gas safety.

³¹⁶ National Transportation Safety Board, "Building Explosion and Fire, Silver Spring, Maryland: Public Meeting April 23, 2016", August 10, 2016, NTSB/PAR-19/01 at <https://go.usa.gov/xmBNC>

³¹⁷ Katie Lange, "BGE settles lawsuit with family of boy killed in home explosion," WBAL TV, Baltimore, August 15, 2014 at <https://www.wbaltv.com/article/bge-settles-lawsuit-with-family-of-boy-killed-in-home-explosion/7088705>

³¹⁸ Tim Fitzsimmons, Ten hospitalized after apparent gas explosion in Maryland apartment, NBC News, March 3, 2022, at <https://news.yahoo.com/10-hospitalized-apparent-gas-explosion-190244127.html>

³¹⁹ Kristina Sgueglia and Elliott C. McLaughlin, Maryland condo explosion leaves 12 people, including 4 kids, injured, CNN, November 16, 2022, at <https://www.cnn.com/2022/11/16/us/maryland-condo-gas-explosion/index.html>

Among other things, minimizing the looming stranded cost problem requires that urgent repairs or replacements needed for safety be distinguished from non-urgent problems. Creative approaches such as electrifying neighborhoods with greater leakage or safety issues with higher priority and decommissioning the gas infrastructure in those neighborhoods should be considered. Networked geothermal heat pump systems could also provide utilities with the option of maintaining a significant rate base; however, this would require a commitment to phase out decommission natural gas infrastructure supplying buildings instead of expanding it.

4.7 Conclusions

The Climate Solutions Now Act has major implications for accelerating the decarbonization of buildings. Specifically, the analysis in this chapter shows that the use of existing natural gas distribution infrastructure is not a realistic option from the points of view of cost, health, or environmental justice. We will examine the policy implications in **Chapter 5**. Suffice it to say here, from an equity point of view, that the recommendation of the Maryland Commission on Climate Change to retrofit all low-income Maryland households by 2030³²⁰ should be adopted as a principal goal both for the energy transition and for economic and environmental justice. The above analysis clearly shows that use of the gas infrastructure should not be included in these retrofits. In fact, the safety objectives that were part of the motivation for the STRIDE law can be joined to the climate objectives of the Climate Solutions Now Act by systematically prioritizing and accelerating the electrification of neighborhoods where there are older pipes and or leaky pipeline infrastructure.

³²⁰ Maryland Commission on Climate Change, 2021 Annual Report, Maryland Department of the Environment, 2021, p. 8, at <https://mde.maryland.gov/programs/air/ClimateChange/MCCC/Documents/2021%20Annual%20Report%20FINAL%20%282%29.pdf>



5.1 Introduction

Energy affordability policy in Maryland must ensure the achievement of two goals:

1. Reduction of energy cost burdens below six percent for all eligible low- and moderate-income households, defined here as households that have incomes of 200 percent or less of the federal poverty level.
2. Full integration of all eligible low- and moderate-income households into the energy transition, including weatherization, access to renewable energy (notably solar), access to demand response, and accelerated electrification of fossil fuel appliances.

The first goal, energy affordability for all, is a longstanding one, and, as a matter of economic justice, is independent of the decarbonization imperatives related to climate change. The two goals are now joined because decarbonization itself creates serious issues that impact affordability and equity. For example, as discussed in **Chapter 4**, the distribution of costs of natural gas would rise steeply as wealthier households electrify. Low-income renter properties are unlikely candidates for electrification given that, without policy interventions, landlords would pay the costs of electrification, while renters would reap the benefits—the classic split incentive problem. Almost all renters pay their heating bills; heat is included in the rent in only about 12 percent of cases.³²¹

Steeply rising energy costs for low-income households would increase energy cost burdens, resulting in greater assistance requirements to maintain affordability or greater dislocation and negative impacts such as ill-health, disconnections, and rising evictions due to energy bill and rent payment conflicts. In fact, both outcomes are likely since, under typical conditions such as those currently prevailing, the majority of households eligible to receive bill payment assistance do not get it (see **Chapter 1**).

Reducing residential fuel use will not only help mitigate carbon emissions, it will also help to reduce in-home emissions of health-damaging air pollutants, providing public health benefits that may be particularly valuable for low-income households, children, the elderly, those with underlying health conditions, and other vulnerable populations.

³²¹ APPRISE, Maryland Low-Income Market Characterization Report, Prepared for the Maryland Office of People's Counsel, October 2018, p. 51, at

Of course, there is the direct impact on decarbonization of a failure to integrate low-income households. Net zero emissions will be difficult enough, given the challenges posed by sectors such as air travel and air freight where no economical technologies for complete decarbonization are currently available. This makes decarbonization of all areas where economical approaches and technologies are available an imperative for decarbonization.

About one-fifth of the households in Maryland have unaffordable energy cost burdens. We estimate that about 200,000 Maryland households have very high energy cost burdens, defined as more than 10 percent of income (**Chapter 2**). Of those, around 50,000 households have energy burdens higher than 30 percent of income, a disastrous level. For reference, according to the guidelines of the U.S. Department of Housing and Urban Development, 30 percent is the affordability limit for the *entire cost of housing, including utilities*.³²²

Further, the analysis in **Chapter 4** shows that, in the absence of strong preventive action, the utility bills of households that now heat with natural gas are likely to increase dramatically if those families are unable to electrify their space and water heating and disconnect from the natural gas system. Specifically, policies and laws that allow further natural gas investments, such as STRIDE, are now at cross purposes with the Climate Solutions Now Act, which requires net zero greenhouse gas emissions by 2045. Low- and moderate-income renters are much more likely to be stuck, being unable to electrify. The above considerations mean that it is essential to join the goal of making energy affordable for all households, especially those with high energy cost burdens, with the integration of those same households into the energy system decarbonization with high priority in ways that can benefit affordability, public health, and climate objectives. The Building Energy Transition report recommended holistic retrofits—including weatherization and heat pumps—of all low-income homes by 2030.³²³

In this chapter we first discuss tools for achieving affordability goals, in particular bill assistance, followed by the systemic ways in which bills can be reduced, such as weatherization and electrification, which simultaneously reduce the need for assistance by lowering bills while meeting climate objectives.

³²² *Glossary of Terms to Affordable Housing*. Washington, D.C.: U.S. Department of Housing and Urban Development, terms archived in 2011. <https://archives.hud.gov/local/nv/goodstories/2006-04-06glos.cfm>

³²³ Maryland Commission on Climate Change, *Transition Plan: A Roadmap for Decarbonizing the Residential and Commercial Energy Sectors in Maryland*, Maryland Department of the Environment, 2021, p. 20, at <https://mde.maryland.gov/programs/air/ClimateChange/MCCC/Commission/Building%20Energy%20Transition%20Plan%20-%20MCCC%20approved.pdf> The term “low-income” was not defined in the report or during the discussions in the Building Sub-Group that oversaw its production. Mark Stewart, Program Manager, Climate Change Program, Maryland Department of the Environment, personal email communication with Arjun Makhijani, December 28, 2022, cited with permission.

5.2 Tools for Affordability

5.2.1 Energy Assistance: The Current Situation

The traditional tool for improving affordability in Maryland has been energy bill assistance, as discussed in **Chapter 1**. One form of assistance helps clear accumulated energy bill arrears to prevent low-income families from being disconnected from utility service. The other is direct bill payment assistance, which reduces energy bills, making the remainder more affordable or less unaffordable. As discussed in **Chapter 1**, direct bill payment assistance has two major components: the federal component is directed mainly at assistance to reduce heating bills; the state component is directed at reducing electricity bills. Both the federal and state components have modest weatherization assistance as well; this helps to reduce energy bills systemically by improving efficiency, including both building envelope efficiency and appliance efficiency. Weatherization is covered in subsequent sections in this chapter; this section focuses on bill assistance.

Current assistance helps reduce energy cost burdens significantly for those who get it. **Table 5-1** below is based on actual utility bill data of assistance recipients. It shows energy costs and the impact of assistance on energy costs burdens for households using different types of heating fuel.

Table 5-1: Sample of households assisted in Maryland's Fiscal Year 2020, with energy cost burdens before and after MEAP assistance, grouped according to main heating fuel.

	All Households	Electricity	Natural Gas	Fuel Oil	Propane	Other
A. Unduplicated Number of MEAP Bill Payment-Assisted Households	88,639	40,986	35,125	7,522	3,296	1,710
B. All Households with 12 Consecutive Months of Bill Data (Main Fuel and Electric)						
1. Unduplicated Number of Households with 12 Consecutive Months of Bill Data (Main Fuel and Electric)	39,998	17,908	15,721	3,718	1,614	1,037
2. Average Annual Household Income	\$16,108	\$15,809	\$16,163	\$16,954	\$16,988	\$16,036

3. Average Annual Total MEAP Benefit per Household (including Heating, Cooling, Crisis, Supplemental Benefits)	\$599	\$381	\$560	\$1,241	\$1,443	\$1,326
4. Average Annual Main Heating Fuel Bill	\$1,210	\$1,541	\$669	\$1,617	\$1,952	\$1,064
5. Average Annual Electricity Bill	\$461	\$0	\$820	\$717	\$1,092	\$1,092
6. Average Annual Total Residential Energy Bill	\$1,671	\$1,541	\$1,489	\$2,334	\$3,044	\$2,156
7. Average Annual Burden Before Receiving MEAP	10.4%	9.7%	9.2%	13.8%	17.9%	13.4%
8. Average Annual Burden After Receiving MEAP	6.7%	7.3%	5.7%	6.4%	9.4%	5.2%
9. Average Percentage Point Change in Energy Cost Burden	3.7%	2.4%	3.5%	7.3%	8.5%	8.3%
10. Average Percentage Reduction in Energy Cost Burden	35.8%	24.7%	37.6%	53.2%	47.4%	61.5%

Source: Table 9, reproduced from: Office of Home Energy Programs, Electric Universal Service Program (EUSP) Proposed Operations Plan for Fiscal Year 2022, , Maryland Department of Human Services, submitted to the Maryland Public Service Commission Docket No. 8903, July 2021, Item # 569, at https://webapp.psc.state.md.us/newIntranet/Casenum/NewIndex3_VOpenFile.cfm?filepath=//Coldfusion/Casenum/8900-8999/8903/Item_569\EUSP_OPERATIONSPLAN_2022.pdf

Table 5-1 shows energy cost burden reduction impact for less than half the households assisted since it is limited to those households for which energy costs were available for a full twelve-month period. The average bills for this group appear to be somewhat lower than is typical (see **Chapters 1 and 2**). Nonetheless, it is clear that even with only heating bill assistance, energy cost burdens are substantially reduced, in many cases below the six

percent affordability threshold.³²⁴ Yet, many households remain above the six percent limit; average burdens for electricity-, fuel oil-, and propane-heated homes post-assistance remain above six percent. A further reduction in energy cost burdens is accomplished by electric bill assistance, not shown above. It should be noted that these are average results; there is a considerable spread in outcomes within each income group and type of heating fuel.

The biggest problem is the low level of participation: most recently, only about 22 percent of the eligible population receive utility bill payment assistance. Within the eligible population, the lowest income group with income below the federal poverty level is also served at a low rate. Only about one-fourth of the families with incomes below the federal poverty level receive any energy assistance,³²⁵ leaving well over 100,000 of the most vulnerable households with unaffordable bills.

Maryland is typical of many other states in its low level of participation in energy bill payment assistance programs. As noted in **Chapter 1**, the number of assisted households has generally declined over the past decade from a high of more than 130,000 in 2011 to just above 80,000 in 2021 and the rate of denials for those who do apply has been rising (**Figures 1-3 and 1-4, Chapter 1**).

Maryland's low participation has many potential causes.³²⁶ Among them:

- Cumbersome documentation requirements, including income and social security numbers;
- Lack of access to broadband;
- Lack of easy access to physical offices for those who prefer that option due to distance or illness for instance;

³²⁴ LIHEAP has required states to report on how well the energy cost burdens of the highest burdened eligible households are being reduced. The performance of the Office of Home Energy Programs has steadily increased since that time. Office of Home Energy Programs, Analysis of the Maryland Executive Budget, FY 2022, Maryland Department of Human Services, 2021, Exhibit 4, p. 10.

³²⁵ Estimated from Table 6, Office of Home Energy Programs, *Electric Universal Service Program (EUSP) Proposed Operations Plan for Fiscal Year 2022*, Maryland Department of Human Services, submitted to the Maryland Public Service Commission Docket No. 8903, July 2021, Item # 569, at https://webapp.psc.state.md.us/newIntranet/Casenum/NewIndex3_VOpenFile.cfm?filepath=/Coldfusion/Casenum/8900-8999/8903/Item_569\EUSP_OPERATIONSPLAN_2022.pdf The Office of Home Energy Programs uses unusual categories of income brackets: 0 to 75 percent and 75 to 110 percent of the federal poverty level, so that the exact number of households below the federal poverty level who were assisted needs to be estimated. We did this by assuming a uniform distribution of households assisted within the 75 to 110 percent bracket.

³²⁶ A report based on interviews with experts describes many of these issues nationally. See "Challenge 3, p. 16 onward in Zuliy Juarez, *Energy Burden & the Clean Energy Transition: Challenges and just solutions from energy assistance practitioners and advocates from around the country*, Just Solutions Collective, 2022, at https://assets-global.website-files.com/5fd7d64c5a8c62dc083d7a25/6246ab05aca2107884fb1632_Energy%20Burden%20and%20the%20Clean%20Transition%20-r4.pdf

- Linguistic barriers;
- Presence of undocumented immigrants in the household;
- Lack of information;
- Lack of adequate customer service to assist applicants (exacerbated during the COVID-19 pandemic);
- The general stigma associated with receiving government assistance, particularly for older persons.

Many of these problems are reflected in Maryland's program requirements and application process, resulting in high denial rates and low participation. For instance, Maryland has a rather forbidding list of application requirements, including "PROOF" (caps in the original) of a highly specific large itemized list of sources of income, including:

- Wages;
- Self-employment;
- Social Security;
- Tips;
- Interest from bank accounts;
- Dividends;
- Rental income;
- And 20 other items.³²⁷

In addition, the income eligibility limits vary according to who lives in the household. The general income eligibility limit is 175 percent of the federal poverty level; but it is 200 percent for households with at least one member who is 67 years old or older. Besides making the application more complex, there is also an element of arbitrariness in it. While the added eligibility is a positive for families with an older member, it excludes other households with similar levels of vulnerability, such as families headed by a single mother. It is well-documented that such households are more vulnerable and more at risk of poverty, among other disproportionate risks.³²⁸

If an adult in the household had no income, a signed declaration to that effect is required. Thus, potentially 28 different attestations (including the no-income attestation) are required just for the income portion of the application. A social security number must be submitted for

³²⁷ Office of Home Energy Programs, State of Maryland, assistance application at https://dhs.maryland.gov/documents/DHR%20Forms/FIA%20Forms/English/OHEP/OHEP_-_Application_2023_EN_Fillable.pdf viewed on October 28, 2022.

³²⁸ Sarah Damaske, Jenifer L. Bratter, and Adrienne Frech, Single Mother Families and Employment, Race, and Poverty in Changing Economic Times, Social Science Research, Vol. 62, February 2017 at <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5300078/>

each household member. Birth dates and citizenship status for each household member are also required. Energy bills must be submitted, rather than just the utility account number. The form must be signed and its contents declared to be true and correct under penalty of perjury. There are explicit cautions about fraud, intentional misrepresentation, and punishment in such cases. Assistance information is available in English and Spanish. The application runs into six pages; documentation requirements are over and above the length of the application. To top it all, the application is explicitly punitive in its tone, reminding applicants that they may face “punishment” for “misrepresentations” or “not telling the truth” in the application.

The searching, detailed, punitive tone of the application entails a loss of dignity in just applying for aid; it appears designed as much a deterrent as an application for assistance. Certainly, many households would be ruled out automatically; for instance, mixed status households in which some have social security numbers and some do not, would be deterred from applying.

The application also presents logistical hurdles. The voluminous documentation must be found and collected; if applying online, the documents must be scanned and uploaded. In the absence of facilities at home; a trip to a commercial facility would be required. In case of a mail-in application, copies would need to be made.

As noted in **Chapter 1**, the number of households helped has been declining over time. The most recent fiscal year, FY 2022, ended on June 30, 2022, is no exception. The number of households helped with bill payment assistance through the first ten months declined again by seven percent to a low of 65,600. Expenditures on the Electric Universal Service Program were only \$64.2 million, despite the fact that revenues were \$118 million,³²⁹ even as hundreds of thousands of eligible households received no help.

Given the complex application and documentation process, the way applicants are served and helped through the process becomes more critical. While direction rests with a central state office, the Office of Home Energy Programs, services are delivered via a network of 25 local offices; about half are local government offices and the rest are “Community Action Partnerships” or non-profit offices. The evident upside is that residents are served by local offices that may know their needs better. The downside is inconsistency of services; for instance, some offices provide in-person help while others do not. There are also inconsistencies in the rates of denial of assistance, since applications are screened by the local offices.

³²⁹ Office of Home Energy Programs. Electric Universal Service Program: Proposed Operations Plan for Fiscal Year 2023. Baltimore, Maryland: Maryland Department of Human Services, July 2022, pp. 2-3, Case No. 8903, Maillog 2416781.

Maryland has made an effort to streamline the process of applying for and receiving various types of assistance by creating a one-stop portal. This site, known as myMDThink,³³⁰ started several years ago. People can apply for food benefits (Supplemental Nutrition Assistance Program), Temporary Cash Assistance Program, Child Protective Services, OHEP, Jobs and Unemployment, Adult Services, and, more recently, utility bill payment assistance, all through a single portal.

Despite the availability of the one-stop shop portal, the long list of requirements has not changed. While the single application process is a big plus, the hurdles of navigating an online application process with extensive documentation requirements remain. There are, inevitably, glitches in the new software, creating additional hurdles.

California provides a welcome contrast. It has close to a 100 percent participation rate in its electricity bill assistance program—essentially all those who are eligible apply and get assistance. Indeed, during the initial period of the COVID-19 pandemic, when unemployment skyrocketed, participation climbed to more than 100 percent because economic dislocation made more people eligible. The participation is so remarkable that the data, by utility, are reproduced in **Table 5-2** below.³³¹

Table 5-2: Participation in California’s electricity bill assistance program, California Alternate Rates for Energy (CARE).

2021 Enrollment and Penetration YTD through July 31						
Utility	Total Residential Customers	Estimated Eligible Customers	Eligible Rate	Customers Enrolled	Penetration Rate	Newly Enrolled Customers
PG&E	5,583,279	1,447,571	26%	1,609,223	111%	139,161
SCE	4,497,048	1,349,716	30%	1,482,236	110%	133,871
SDG&E	1,372,319	293,584	21%	342,851	117%	35,253
SoCalGas	5,672,733	1,712,462	30%	1,839,181	107%	157,818
Total	17,125,379	4,803,333	28%	5,273,491	110%	466,103

Source: Pacific Gas & Electric, Southern California Edison, San Diego Gas & Electric, and SoCalGas, Joint IOU Report of the CARE and ESA Programs, Slide Deck presented at the Low-Income Oversight Board Meeting, September 29, 2021.

³³⁰ <https://mymdthink.maryland.gov/home/#/>

³³¹ Pacific Gas & Electric, Southern California Edison, San Diego Gas & Electric, and SoCalGas, Joint IOU Report of the CARE and ESA Programs, Slide Deck presented at the Low Income Oversight Board Meeting, September 29, 2021, at <https://liob.cpuc.ca.gov/wp-content/uploads/sites/14/2021/09/Item-9-IOUs-Consolidated-Template-revised.pdf>

A key to the high participation rate is that no documentation is required with the application. The application asks for the account holder's name and address as well as the utility account number. No other personal identifying information is required; names of other household members or their social security numbers or driver's license numbers are not required. So far as other household members are concerned, the only information needed is the number of adults besides the applicant and the number of children in the household. A simple signature suffices—without further attestation or legal jeopardy attached to that signature. The applicant can choose from nine languages for communications from the utility, including English, Spanish, Mandarin, Cantonese, Vietnamese, and Hmong. The form, including eligibility information, is just two pages long; the application part is just one page.

It is not that California's program is without its difficulties or complexities. Post-assistance verification is done for selected assistance recipients. The requirements for documentation of income are extensive and comparable to Maryland, though other documentation requirements are not as extensive or intrusive. For instance, social security numbers are not required. While the applicant must certify that the information provided is true, there is no mention of "punishment."³³² Assistance recipients do get excluded from the program *post facto* for failing to provide adequate documentation.

Asking low-income people who are going to be bumped from assistance for refunds post-facto is a tall order—and complex on both sides of the equation. Moreover, assistance in California is provided in the form of lower rates; it does not guarantee that the resultant bill at the lower rate will be affordable. It is much more likely to be so for people at the higher end of the eligibility range (i.e., closer to 200 percent of the federal poverty level) than, say, at 50 percent or 100 percent of the poverty level. While overall participation is high, it can be, and is, low in some rural areas with very low population density.³³³ But these are mere quibbles compared to the massive failure of enrollment in Maryland's program and the failure to assist tens of thousands of families who do apply.

California is not the only state that makes it easy to apply for assistance. For instance, the energy utility in the Portland, Oregon area can be approached in 15 different languages (including English and Spanish) to get a discount on the household energy bill of up to 25 percent over and above whatever other assistance the family may be getting. The webpage is welcoming; it says it is "super easy" to apply. The application form is very similar to the one used in California. While there is an explanation of what income sources should be counted in

³³² Pacific Gas & Electric, CARE Post-Enrollment Verification Request Form at https://www.pge.com/pge_global/common/pdfs/save-energy-money/help-paying-your-bill/EN_pev_request_form.pdf viewed on November 1, 2022.

³³³ Ibid. pp. 4-5.

providing the statement of household income, it says clearly that “no financial documents are required.”³³⁴ This new supplemental assistance plan was launched in 2022.³³⁵

The best experience with self-attestation appears to be in Maryland itself. Civic Works, based in Baltimore, is a non-profit organization; it has been carrying out weatherization and efficiency programs in low-income households since 2009 in cooperation with both state and Baltimore City agencies. Civic Works uses self-attestation as part of the qualification process for eligibility. It does have a random post-weatherization income check; customers are informed in advance that there may be such a check. Over all these years, *Civic Works has not found a single case of fraud*; only minor discrepancies have been discovered.³³⁶

There are four principal issues associated with providing low- and moderate-income households with assistance sufficient to make household energy costs affordable:

- What are the policies, regulations, incentives, and procedures needed to have essentially universal enrollment in assistance programs of all the households that are income-eligible to do so?
- What is the best way to ensure that the energy cost burden for all eligible households is made affordable (defined in this report as six percent of income or less)?
- What level of assistance funds would be required to meet a universal affordability goal and, as a corollary question, where might these funds come from?
- Since the funds needed for universal affordability are far greater than those available now, are there systemic ways to reduce funding requirements, while maintaining the affordability goal? This is the question where affordability connects with the transition to a clean, renewable, efficient, and affordable energy system.

Self-attestation would be a big step but it is not a cure-all. A part of the assistance money is from the federal government’s LIHEAP program; those funds require documentation before they can be disbursed to recipients. In California, the reduced rate program is administratively separate from the utility-run programs that provide discounted electricity (30 to 35 percent less than the normal rate) and discounted natural gas (20 percent less than the normal rate).³³⁷ However, even in this case, the application is much simpler than the one used in Maryland. For instance, only the applicant is required to provide a social security number. It is also more respectful of the dignity of the applicant who is not sternly reminded about

³³⁴ See PGE’s assistance webpage at <https://portlandgeneral.com/income-qualified-bill-discount>. The application form is at <https://portlandgeneral.com/income-qualified-bill-discount-form>, viewed on October 30, 2022.

³³⁵ PGE News Release, “PGE Launches New Income-Qualified Bill Discount Program, Portland General, April 18, 2022 at <https://portlandgeneral.com/news/pge-launches-new-income-qualified-bill-discount-program>

³³⁶ Schwartz, E. Civic Works, personal email communication, December 17, 2021.

³³⁷ California Public Utilities Commission, California Alternate Rates for Energy,

punishment even though they are required to attest to the contents of the application under penalty of perjury.³³⁸

It should also be noted that, in contrast to essentially 100 percent participation in the utility program, participation in California's LIHEAP program is very low—just six percent in 2019 (**Figure 1-1, Chapter 1**). We have not examined the causes for this, but note that the rebate in the utility gas rate serves a similar function of reducing heating bills without the obstacles presented by LIHEAP documentation requirements. Maryland, which is typically colder than California, has no comparable program.

In addition, there are also related approaches that would systemically reduce bills and enable all people, including low- and moderate-income households, to participate in the energy transition; we will cover these in this chapter as well.

5.2.2 Approach to Assistance

Different approaches are used to directly reduce the energy cost burdens of low- and moderate-income families:

- **Direct bill payment assistance:** This is the model used in Maryland, where assistance is used to provide a credit on utility bills and reduce the amount payable by the customer. Ratepayer and RGGI-funded electricity bill assistance (EUSP) and federal heating bill assistance (MEAP) are disbursed in this way. Periodic clearance of long-accumulated arrears is also done by bill credits.
- **Discounted rates:** This is the California model, whereby a lower electricity or gas rate for eligible households reduces energy bills. Known as CARE (California Alternate Rates for Energy), the “program offers a 30-35% discount on your electric bill and a 20% discount on your natural gas bill.”³³⁹
- **Percentage of income payment plan (PIPP):** This approach aims at making energy bills affordable by providing bill assistance sufficient to lower the energy cost burden to a specified percentage of income, usually six percent.

Each plan has its advantages and disadvantages. The discounted rates approach has the merit of great simplicity of concept and administration. It does not require legislative or regulatory

³³⁸ CALIHEAPApply.com - California's Online LIHEAP Application includes a very simple, easy to follow step-by-step instruction video, at <https://www.caliheapapply.com/> viewed on November 11, 2022.

³³⁹ California Public Utilities Commission, CARE?FERA Program: California Alternate Rates for Energy,” at <https://www.cpuc.ca.gov/lowincomerates/> viewed on November 11, 2022. <https://www.cpuc.ca.gov/consumer-support/financial-assistance-savings-and-discounts/california-alternate-rates-for-energy> viewed on November 1, 2022. The 30 to 35 percent electricity rate discount applies to utilities with more than 100,000 customers. For those with fewer customers, a 20 percent discount is offered.

action to raise the amount of funds when the need increases. In addition, California's simple application procedure with self-attestation of income, makes for high participation without high overheads for aiding people to fill out the forms, find, copy, and upload documents to achieve it. The California program also makes provision for encouraging efficiency among high electricity users by stating that a utility may require a CARE program participant whose electricity consumption is more than 400 percent of a "baseline" amount to "to participate in the Energy Savings Assistance Program (ESAP), which includes a residential energy assessment, in order to provide the CARE program participant with information and assistance in reducing his or her energy usage."³⁴⁰

One disadvantage of rate discount plans is that, for a given percentage rate discount, utility bills become less affordable as rates rise. Thus, even as low- and moderate-income customers receive a deteriorating level of assistance from the point of view of energy cost burden, the costs to ratepayers of providing that assistance increases. For instance, a regular rate of \$0.20 per kilowatt-hour, discounted 33 percent to \$0.133 per kWh would result in an energy bill of \$1,000 for a low-income customer using 7,500 kWh a year. At an income of \$20,000 per year, the energy cost burden would be reduced from 7.5 percent to five percent. The cost to other ratepayers would be \$500.

If the rates rise to \$0.30 per kWh (as they have done in some cases), the same percentage discount would now result in the low-income customer having a bill of \$1,500 per year, which means an energy cost burden of 7.5 percent, the same as before assistance when the rate was \$0.20/kWh. Even as the bill becomes unaffordable for the household receiving assistance, the cost to other ratepayers increases by 50 percent, from \$500 to \$750 per year. Thus, neither the party getting assistance nor the party funding it are insulated from the affordability consequences of rising rates.

Another feature that could be seen as a drawback is that a rate discount lowers the bill of households with very different incomes but same electricity use by the same amount. In the example above the electricity cost burden for a family with an income of \$20,000 is reduced from 7.5 percent to five percent, which is possibly affordable (depending on whether there is a natural gas or propane bill or not). For a household with \$10,000 income, the percentage burden drops by more, from 15 percent to 10 percent, but the final bill remains unaffordable.

The Maryland model of direct bill payment assistance that is paid to utilities is similar to the rate discount program in one way: by crediting the assistance amount to the customer's bill, the low-income assistance recipient sees a lower, more affordable bill than would be the case

³⁴⁰ California Public Utilities Code 739.1(i) at https://california.public.law/codes/ca_pub_util_code_section_739.1 viewed on November 1, 2022.

without assistance. In many cases, the energy cost burden is reduced to less than six percent, which is the affordability threshold.

Two other advantages over the rate-discount program are noteworthy.

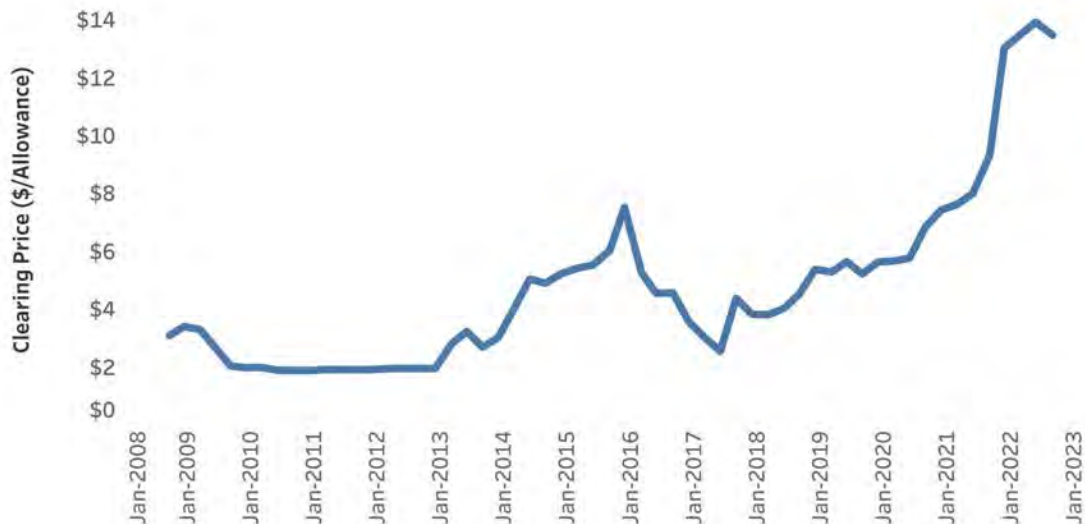
First, the federally-funded LIHEAP heating program can include households that use non-regulated fuels for heating, notably fuel oil and propane. Energy cost burdens for households using these fuels are generally higher (other things being equal), since they are more expensive fuels. Maryland, like other mid-Atlantic and northeastern states, has a significant number of households using these fuels; they are generally in rural areas. Their inclusion in energy assistance is an element of urban-rural equity that is important for both assistance and energy transition policies to take into account.

Second, the programs can be designed so that assistance can be preferentially directed towards households at the lower end of the income spectrum, families with disabled or ill members, and families with children. On the other hand, the funds available for bill assistance are limited and participation is low. High participation would reach more families but reduce the impact per family, since the amount of assistance funds available does not increase with the number of applicants or eligible households.

Specifically, in Maryland, EUSP, the electricity bill assistance program, is funded in part by a per-kilowatt-hour charge on electricity sales; the amount available is thus automatically limited by the total sales. Unlike the discounted rates approach, the available funds do not increase as rates rise and electricity bills become less affordable.

A part of the revenues from the sale of allowances under the Regional Greenhouse Gas Initiative (RGGI) is also devoted to electricity bill assistance in Maryland; it is the other major source of funds (see **Chapter 1**). The amount of this funding depends on the market price of each unit, which represents a metric ton of CO₂; allowances must be purchased at auction by electric utilities that have CO₂-emitting power plants. **Figure 5-1** shows the auction clearing prices of permits over time, with each permit representing a metric ton of CO₂ emissions.

Figure 5-1: Auction Clearing Prices of CO₂ permits in the Regional Greenhouse Gas Initiative. An allowance represents a metric ton of CO₂.

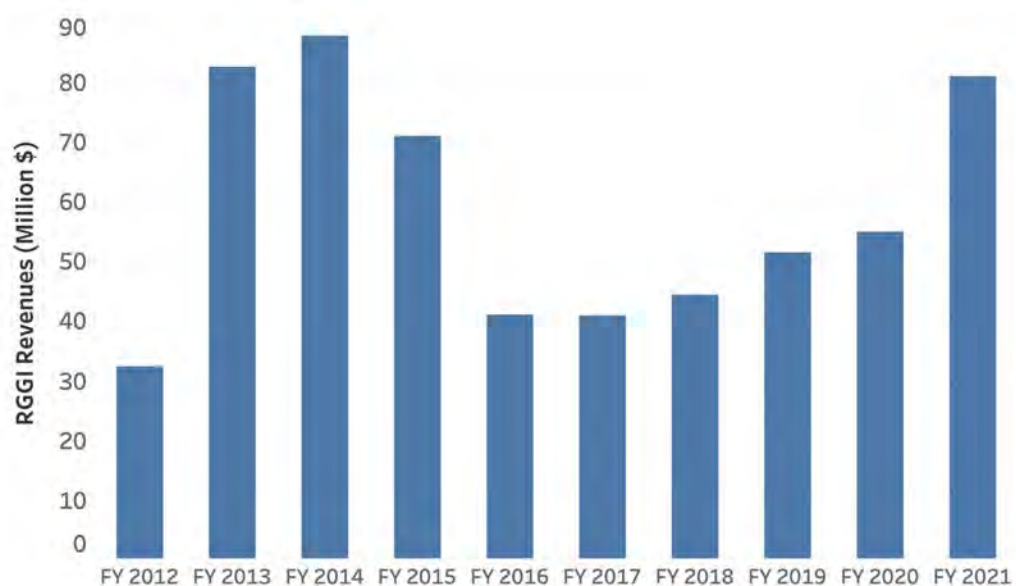


Source: Regional Greenhouse Gas Initiative, *Allowance Prices and Volumes*, at <https://www.rggi.org/auctions/auction-results/prices-volumes>

The available funds fluctuate with each auction; hence funding increases are not necessarily aligned with funding needs. Prices rose from 2012 to 2015 and then fell sharply for the next two years. A reduction in the total number of permits available (to restrict electricity sector CO₂ emissions) has resulted in an increasing permit clearing price tendency since late 2017. Of course, total revenues rise less than the allowance price when the number of allowances declines. **Figure 5-2** shows the annual revenues that accrued to Maryland from the sale of RGGI allowances, indicating the volatility of RGGI revenues.

Unlike the rate-discount approach used in California, the available funds in the bill-payment assistance model do not increase with the need, as for instance when electricity or natural gas rates increase, pushing up energy cost burdens.

Figure 5-2: Maryland annual revenues from the sale of Regional Greenhouse Gas Initiative allowances by fiscal year (from July 1 to June 30 of the next year).



Sources: Data compiled from Annual RGGI reports for FY 2016, FY 2018, FY 2020, and FY 2021, downloaded from <https://energy.maryland.gov/Pages/reports.aspx>

Our estimate of the total affordability gap (**Chapter 2**) is about \$360 million per year (based on Standard Offer Service rates for electricity and gas), but only about \$120 million or so is available from current assistance sources—far short of meeting the need. The gap for fully funding a PIPP is therefore about \$240 million per year. This includes all households with energy cost burdens over six percent; current eligibility criteria for assistance would leave out tens of thousands of them.

It should be noted that the administrative expenses associated with Maryland’s program are significant. The allocation for administrative expenses for Fiscal Year 2022, including for the local offices accepting and processing assistance applications, was \$11.5 million³⁴¹—about \$130 per assisted household. Much of this expense is the cost of processing applications that have voluminous documentation requirements, including verification of income, social

³⁴¹ Office of Home Energy Programs, *Electric Universal Service Program (EUSP) Proposed Operations Plan for Fiscal Year 2022*, Maryland Department of Human Services, submitted to the Maryland Public Service Commission Docket No. 8903, July 2021, Item # 569, Attachment A, p. 31, at https://webapp.psc.state.md.us/newIntranet/Casenum/NewIndex3_VOpenFile.cfm?filepath=//Coldfusion/Casenum/8900-8999/8903/Item_569\EUSP_OPERATIONSPLAN_2022.pdf

security numbers, etc. Simplification of this process would free up funds for expanding participation.

A smaller, but still significant problem is the different income qualification levels for different programs and income groups. As noted in **Chapter 1**, the general income eligibility level for qualifying for assistance is income equal to or less than 175 percent of the federal poverty level. A recently enacted law has increased the income threshold to 200 percent for households with at least one member who is at least 67 years old. The threshold for weatherization assistance is 200 percent of the federal poverty level or 80 percent of the Area Median Income, whichever is higher in a particular county. This is the most expansive income qualification criterion. It is even more confusing because assistance for all these households is handled through a common application.

Expanding eligibility to be the same as for weatherization, up to 200 percent of the federal poverty level or 80 percent of area median income, whichever is higher, would cover essentially all cost burdened households and simplify the full integration of assistance with energy transition for cost burdened households.

We turn now to the Percentage of Income Payment Plan (PIPP), which combines the strengths of the rate-discount approach and the bill reduction approach. However, the path to securing such a program is not without its obstacles.

5.2.2.1 Percentage of Income Payment Plan

Percentage of Income Payment Plans (PIPPs) limit the total energy cost burdens of eligible low- and moderate-income households to a certain percentage of household income—usually six percent. In theory, PIPPs combine the advantages of the rate-discount approach and the bill-payment approach to reducing energy cost burdens.

The biggest advantage is that a reduction of energy cost burden to the defined affordable amount is guaranteed under the program. That does not reduce the obstacles to enrollment, but it does assure that those who do enroll have a legally defined maximum energy cost burden. This guarantee will become increasingly important as climate extremes drive up energy bills—especially for cooling, but also for heating in some years and places. As is clear by now, average temperature increases can be and are accompanied by more severe winters or more severe periods (such as “polar vortex” periods) within a winter that is warmer on average. Thus, heating bills may also rise, disrupting a family’s finances. Given that low-income household finances are usually precarious, there is an asymmetry of consequences—the surpluses when bills are lower are absorbed by other unmet needs, but

the deficits can result in food-medicine-rent-utility bill payment conflicts that can lead to disastrous consequences including ill-health and becoming unhoused.

As we discuss below, weatherization is one way to reduce energy cost burdens by lowering overall energy demand. However, access to weatherization is considerably more difficult for renters, since audits and retrofits require the landlord's permission for access to the property. This is sometimes denied.³⁴² If a PIPP is in place, renters can still have affordable bills, though the cost would be higher than with weatherization. Those additional costs are borne by the non-low-income part of society—some combination of ratepayers and taxpayers. As a result, a PIPP creates a financial interest in the economically better-off sections of society to invest in weatherization and other means of systemically reducing energy bills because that also reduces assistance requirements.

The seriousness of the energy cost burden problem and the inadequacy of an assistance program that neither reaches most eligible households nor makes energy cost burdens affordable for all the households it does reach has been recognized in Maryland for many years. Specifically, the Public Service Commission opened an inquiry in 2011 into a PIPP for low- and moderate-income households in the state. Under such a plan, an eligible household would get sufficient assistance to bring its energy cost burden down to six percent, independent of how much above that threshold it might be initially. The Technical Staff of the Commission and the Office of People's Counsel, the official ratepayer advocate, worked together to examine the program. In 2012, both the Commission Staff and Office of People's Counsel recommended that Maryland adopt such a plan under the rubric of the Affordable Energy Program, which was the phrase adopted for a PIPP proposed for Maryland. Its main features were to be:³⁴³

- The energy cost burdens of households with incomes equal to or less than 175 percent of the federal poverty level would be limited to six percent by providing direct bill credits to electricity and, if applicable, natural gas bills. Since propane and fuel oil are not regulated by the Commission, they were not covered by the recommendation. In case a household had both gas and electric service, a three percent limit would be applied to each bill.

³⁴² Arjun Makhijani, Christina Mills, and Annie Makhijani, *Energy Justice in Maryland's Residential and Renewable Energy Sectors*. Takoma Park Maryland: Institute for Energy and Environmental Research, 2015, p. 66, at <https://ieer.org/wp/wp-content/uploads/2015/10/RenMD-EnergyJustice-Report-Oct2015.pdf>

³⁴³ Maryland. Public Service Commission. Staff. *Affordable Energy Program ("AEP") Proposal*. Before the Public Service Commission, In the Matter of Low-Income Energy-Related Customer Arrearages and Bill Assistance Needs of Maryland: PC 27 [Public Conference PC 27]. Baltimore: PSC, November 1, 2012, p. 4, at https://webapp.psc.state.md.us/newIntranet/AdminDocket/NewIndex3_VOpenFile.cfm?FilePath=//Coldfusion/AdminDocket/PublicConferences/PC27//12.pdf

- The pre-program arrearages would be cleared through special one-time grants at the start of the program, requiring some contribution from most households, with the rest provided by assistance funds.
- The Affordable Energy Program would be coordinated with weatherization programs so as to reduce energy bills and, hence, the amount of assistance needed to meet the six percent affordability criterion. Households with very high energy consumption would be prioritized.
- Routine periodic clearance of arrearages would be ended.
- Arrearage clearance would be considered if there were an extraordinary circumstance such as the loss of a job or a severe illness.

The overall cost of the program was estimated at \$250 million.³⁴⁴ While regulated utilities did not oppose the program outright, recognizing its benefits in making bills more affordable, they asked that the program not be enacted until there was much more study and examination of a variety of issues, including impacts on non-income ratepayers, conversion of an assistance program to an entitlement program, and assistance costs much above assistance levels at that time (2012). Baltimore Gas and Electric also made a remarkable statement about personal responsibility and root causes of failure to pay utility bills in full:³⁴⁵

BGE said then [in March 2012] and reiterates now [November 2012] that assistance is more likely to help move customers toward self-reliance if it is tied to some elements of personal responsibility, energy efficiency and conservation, and financial literacy/budget counseling.

In addition to enhanced conservation and efficiency measures, BGE argued this might entail some customer requirements for ongoing receipt of assistance, such as a history of utility payments and attendance at some prescribed set of energy education and/or financial literacy or budgeting programs, to address some of the root causes of insufficient bill payment.

The “root causes of insufficient bill payment” were not further discussed in the company’s comment. Yet, they are well known. Generally, the causes include low wages, high rents, lack of health insurance with employment, ill-health due to a variety of factors, including living in food deserts, and the well-documented conflicts between the various financial needs. The

³⁴⁴ Ibid. p. 28.

³⁴⁵ *Comments of Baltimore Gas and Electric Company: In the Matter of Low-Income Energy-Related Customer Arrearages and Assistance Needs*, filed as part of Public Conference 27, Maryland Public Service Commission, November 30, 2012, pdf pp. 2-3, at https://webapp.psc.state.md.us/newIntranet/AdminDocket/NewIndex3_VOpenFile.cfm?FilePath=//Coldfusion/AdminDocket/PublicConferences/PC27//16.pdf

most frequent and important conflicts are that families are forced to choose between paying rent, paying utility bills, and buying food and medicines. Almost five percent of those who have received heating bill payment assistance at least once in five years lose their homes due to such conflicts; there are about 7,000 evictions a year in Baltimore City alone (see below). Budgeting programs and financial literacy cannot address these fundamental problems, though they might rearrange them.

As is well and widely understood, most low-income households are renters; weatherization, more efficient appliances, and more efficient heating systems are therefore typically beyond their control. The “split-incentive” problem—costs to the landlord, benefits to the renter—is well understood as a structural obstacle, also outside the control of renters. Living in poorly insulated rental housing is also a cause of high energy bills. The 2015 IEER energy justice study estimated that on average, low-income households have about 50 percent more heating consumption per square foot than the average; as is well understood, the average can be improved significantly, with obvious implications for the greater potential for savings for low-income households. To imply that “insufficient bill payment” was somehow a failure of personal responsibility in the context of these well-known causes is to deflect attention from the causes, and hence also the solutions.

Finally, third party supply in Maryland’s deregulated electricity and gas sectors also significantly increases energy bills of residential subscribers in general, and of low-income households in particular. The problem has become particularly acute since the “Purchase of Receivables” regulation that put the risk of failure to pay due to high rates on ratepayers instead of the vendors of third-party supply. High third-party energy supply rates actually siphon off millions of dollars of assistance funds that go to the suppliers instead of reducing energy cost burdens. As noted in a 2018 Abell Foundation report, the Purchase-of-Receivables regulation left the third-party suppliers free to charge high rates without fear that the subscribers would fail to pay; the third party suppliers were guaranteed payment because the utilities paid them automatically, whether the customer paid the bill or not. The problem ballooned once this “moral hazard” was created.³⁴⁶ A rough estimate of the added energy cost burden on low- and moderate-income households for the year 2021 is on the order of \$30 million for electricity bills and \$7 million for natural gas bills.

The impact on energy cost burdens of low-income subscribers of high third-party energy supply costs has been serious enough that the Maryland General Assembly passed a law in 2021 prohibiting third party supply rates above the utility “Standard Offer Service” for low-

³⁴⁶ Laurel Peltier and Arjun Makhijani, *Maryland’s Dysfunctional Residential Third-Party Energy Supply Market: An Assessment of Costs and Policies*, Abell Foundation, Baltimore, Maryland, December 2018, p. 12 at <https://ieer.org/wp/wp-content/uploads/2018/12/Third-Party-Energy-Report-final-121718.pdf>

and moderate-income households receiving energy bill assistance.³⁴⁷ That is only a partial solution; it leaves the majority of the problem unsolved, however, since almost 80 percent of low- and moderate-income households do not get assistance even though they are eligible.

PIPPs that have near-universal enrollment will, in general, be more expensive than other assistance plans. This is because the various present-day combinations of low-enrollment and insufficient assistance to enrollees means the current budgets fall far short of filling the actual affordability gap. Funding PIPP adequately and ensuring essentially universal enrollment are the two major challenges in generally lowering costs to affordable levels. We have discussed lowering the barriers to enrollment. The political will for appropriating sufficient funds can be increased in two ways:

- a. Quantifying, so far as possible, the very substantial non-energy benefits of affordable energy to non-low-income households;
- b. Reducing energy bills of low- and moderate-income households significantly by weatherization, community solar investments, electrification, and demand response sufficiently to greatly decrease the amount of assistance needed to make energy bills affordable and, so far as possible, reducing the amount of assistance needed to zero in all cases except the very lowest income brackets, where increases in income would be the most basic remedy.

We cover the systematic reduction of bills below and then show how the assistance and bill reduction aspects work together. In the rest of this section we estimate some of the quantifiable benefits of universally affordable energy and the funds needed in case universal enrollment is achieved.

5.3 Non-energy Benefits of Affordable Energy

Making energy affordable for all would have significant health and economic benefits for non-low-income households and for society at large. Many of these can be considered under the rubric of non-energy benefits, such as improved health and reduced costs associated with emergency room visits and homelessness. Taking such benefits into account was not a regulatory norm in 2012, when the proposed Affordable Energy Program was set aside. However, in 2015, when considering energy efficiency program costs and benefits, the Maryland Public Service Commission decided that if societal costs of efficiency programs were going to be considered then societal benefits—including “non-energy benefits”—should be included as well. While the Commission did not state that non-energy benefits should be

³⁴⁷ Maryland Senate, “Electricity and Gas – Energy Suppliers – Supply Offers,” Senate Bill 31, 2021, (cross-filed with House Bill 397) at <https://mgaleg.maryland.gov/2021RS/bills/sb/sb0031E.pdf>

considered for energy assistance programs as well, the reasoning clearly applies to any energy program on which public funds—ratepayer or taxpayer funds—are spent; the former are under the purview of the Public Service Commission; the latter under the Executive branch (for spending) and the legislature (for accountability).

Affordable energy and healthy homes will not remove all financial conflicts, but there is evidence that they could be significantly diminished. Maryland-specific data can help us identify order of magnitude estimates of at least some of the non-energy benefits of PIPPs.

Consider the following example provided by a pilot program in Baltimore. It implemented a holistic approach, as adopted by the Green and Healthy Homes initiative, in its retrofits. The result was a dramatic reduction in mortgage foreclosure notices, indicating much greater housing stability, as recounted in Makhijani, Mills, and Makhijani 2015:

Out of a total of 580 houses pre-intervention, there were 57 total foreclosure notices to 49 different households (some received more than one notice in the study period). Post-assistance, the numbers were 7 total notices to 6 households out of a total of 580. **This means over 8 percent of the households received notices prior to participation and only about 1 percent received such notices after participation—more than an eight-fold decrease.**³⁴⁸

It is difficult or impossible to untangle the various financial stresses that lead to a particular eviction or foreclosure. However, the rent-energy bill conflicts are significant in the picture. For one thing, tenant payment of utility bills is a common part of many rental contracts. Low-income families who get federal Section 8 vouchers to assist with rent payment must stay current on their energy bills.³⁴⁹

There is direct evidence of the rent-energy bill conflicts from the detailed study on evictions done in Milwaukee, Wisconsin by Matthew Desmond. Since families are protected from utility shut-offs in the winter, many low-income families put off paying their utility bills, including in the effort to stay current on rent. The prohibition of utility shut-offs ends in the spring, with

³⁴⁸ Arjun Makhijani, Christina Mills, and Annie Makhijani, *Energy Justice in Maryland's Residential and Renewable Energy Sectors*. Takoma Park Maryland: Institute for Energy and Environmental Research, 2015, p. 91 (emphasis in the original), at <https://ieer.org/wp/wp-content/uploads/2015/10/RenMD-EnergyJustice-Report-Oct2015.pdf>

³⁴⁹ The federal program that provides vouchers to assist eligible households with rent, known commonly as the “Section 8 program,” is governed by federal regulations promulgated by the Housing and Urban Development Department at 24 CFR Part 982. The tenant obligations include “maintain[ing] the unit in accordance with HQS [Housing Quality Standards]” (24 CFR 882.404a); that obligation includes the requirement to “pay for any utilities that the owner is not required to pay for, but which are to be paid by the tenant” (24 CFR 982.404(b)). Failure to do so could result in the termination of the assistance. The full regulation is at <https://www.ecfr.gov/current/title-24/subtitle-B/chapter-IX/part-982>

many families having accumulative significant arrears. As they start paying these off, they fall behind on rent. Summer becomes a tragic season of increasing evictions.³⁵⁰

There is no data specific to the state of Maryland on the various impacts of the conflicts between unaffordable energy bills and other needs like paying rent and buying medicines. However, some indication of the magnitude of the results of such conflicts can be found in data from Baltimore City, where landlords evict 7,000 families each year.³⁵¹ The court that adjudicates these cases deals with 150,000 cases each year³⁵² in a city that has only about 126,000 households who rented their homes, amounting to 52.3 percent of the occupied houses in the city; 20 percent of people in the city live with incomes below the poverty line.³⁵³ We estimate that three-fourths of those households with incomes less than the federal poverty level rent their homes. Moreover, the median income in this majority-Black city (\$52,000 per household^{354,355}) is only about 60 percent of the median of the state as a whole (\$90,000 per household)).

The rate of eviction notices average more than one per year per residential rental property in Baltimore City. Since the majority of low- and moderate-income households are renters, we estimate that on the order of one in ten low- and moderate-income households in Baltimore City experience an eviction each year and that these households would typically receive multiple eviction notices.

IEER's energy justice report also estimated that each homelessness event, besides being very harmful to the family evicted, would also cost the rest of society about \$28,000 in costs of shelter and added emergency room visits;³⁵⁶ in 2022 dollars, it would be well in excess of \$30,000. Assuming 1,000 homeless families (just 15 percent of the evictions in Baltimore), the added cost of these two items alone would be \$30 million. If the costs of dislocation, loss of educational opportunity, and loss of jobs, and other impacts are taken into account, the statewide impact would be considerably larger.

³⁵⁰ Matthew Desmond. *Evicted: Poverty and Profit in the American City*. New York, New York: Crown Publishers, 2016, pp. 15-16.

³⁵¹ Public Justice Center, Rent Court and Eviction Reform, at <http://www.publicjustice.org/en/rent-court-and-eviction-reform/> viewed on October 26, 2022.

³⁵² Dan Pasciuti and Michele Cotton, How Renters Are Processed in the Baltimore City Rent Court. Baltimore, Maryland: Public Justice Center, December 23015, p. iv at http://www.publicjustice.org/wp-content/uploads/2019/09/JUSTICE_DIVERTED_PJC_DEC15.pdf

³⁵³ Calculated from Baltimore City, Quick Census Facts, at

³⁵⁴ Data USA: Baltimore City, at <https://datausa.io/profile/geo/baltimore-city-md/> viewed on October 26, 2022.

³⁵⁵ In **Chapter 2** we present that the BIPOC population in Baltimore City has an even lower median income of \$44,000

³⁵⁶ Ibid. p. 90.

This accounting of non-energy costs does not take into account the majority of families who become unhoused because they take shelter with family or friends. They would be counted as “homeless” in the broader definition of that term by the federal Department of Health and Human Services. That term includes people who do not have “a fixed, regular, and adequate nighttime residence” and people who “will imminently lose their housing” including if they have an eviction notice to vacate the home within 14 days. By this definition, the number of homeless people in Maryland could total many thousands of families each year, given that there are about 7,000 evictions each year in Baltimore City alone.

There are many other costs as well. A 2015 survey of the consequences of eviction found increased depression, increased material deprivation, and increased stress for two years or more after an eviction. Homeless people experience increased assault and unemployment. The latter involves loss of income to the person and loss of tax revenue to the government. More complete estimates of quantifiable costs of homelessness range from \$35,000 to \$111,000 *per person per year*³⁵⁷—an average of over \$70,000 per year. Lower stress, being able to buy medicines and take the full dose are examples of non-energy health benefits that are likely to be realized in at least partial measure due to affordable bills.

The average duration of homelessness due to evictions is about seven months.³⁵⁸ Typically, an eviction means that more than one person loses their home. Assuming an average of two people become homeless for seven months per eviction or foreclosure, a more complete cost estimate per eviction or foreclosure is about \$80,000 (rounded). Of course, the loss of a sense of security and safety, the loss of dignity, and the consequences of constant stress upon relationships and family cannot be quantified in money terms. Applied to 1,000 households, the total amounts to \$80 million per year. The entire \$80 million cannot be attributed to rent-mortgage conflicts with energy bills alone; yet there are also many costs not taken into account. For instance, it does not include the people who lose their homes who take shelter with family and friends, or the increased crowding, health risks, stresses, and dislocation involved. Nor does it count the increased pediatric asthma from indoor air pollution, the ill-health caused when people take partial doses of medicine to save money to pay their utility bills or rent or when they go hungry for the same reason. It does not take into account loss of workdays or the resultant lost tax revenue. The non-energy benefits are likely to be much larger than the very partial accounting above. In the following calculations, we use \$120

³⁵⁷ Arjun Makhijani, Christina Mills, and Annie Makhijani, *Energy Justice in Maryland's Residential and Renewable Energy Sectors*. Takoma Park Maryland: Institute for Energy and Environmental Research, 2015, pp. 90-91. Seven months was the weighted average period between homeless families and single people. at <https://ieer.org/wp/wp-content/uploads/2015/10/RenMD-EnergyJustice-Report-Oct2015.pdf>

³⁵⁸ Ibid., p. 90. Seven months was the weighted average period between homeless families and single people. at <https://ieer.org/wp/wp-content/uploads/2015/10/RenMD-EnergyJustice-Report-Oct2015.pdf>

million per year (i.e., 50 percent more than the estimate for homelessness alone) to estimate the avoided costs from 2038 onward of having healthy, affordable energy.³⁵⁹

In brief, the consequences to the affected low- and moderate-income families as well as to the non-low-income part of society are severe and large. An order of magnitude estimate (present value at a three percent discount rate) of avoided damage is about \$3 billion. This is about the same as the present value of the net cost of assistance and full integration into the energy transition to the year 2100 (see **Sections 5.3 and 5.4.6**).

In the following sections we will use typical energy consumption values for a natural gas- and a fuel oil-heated household at three different income levels in order to illustrate the economics of integration of low-income households into the energy transition. We will use a three-person household at 50 percent, 100 percent, 150 percent, and 200 percent of the federal poverty level to estimate the evolution of energy cost burdens. We will examine cost burdens for each facet of energy transition integration for households with the current rate/cost structure and in cases where low-income households are stranded on the fossil fuel system when non-low-income households have transitioned to an all-electric mode. Fuel oil-heated homes are assumed to have electric water heating and cooking, hence the larger electricity consumption relative to natural gas heated homes. The economics of propane heated homes will be similar. **Table 5-4** shows the possible evolution of the energy costs of typical fossil fuel heated households from 2021 to 2040.

Table 5-4: Typical energy costs and burdens of a fossil fuel heated household in 2021 and 2040.

Typical Household In 2021		
	Gas-heated household	Fuel oil-heated household
Fossil fuel consumption, MMBtu	70	50
Electricity consumption	7,000	12,000
Fossil fuel rate, \$/MMBtu	\$12	\$20
Fossil fuel cost, \$/year	\$840	\$1,000
Electricity rate, \$/kWh	\$0.13	\$0.13
Electricity cost	\$917	\$1,572

³⁵⁹ This is admittedly an order of magnitude calculation that should be refined with a fuller accounting of the non-energy benefits of affordability, housing security, and better health both for the households concerned and or society at large. It should be noted, however, that the cost calculations in Chapter 5 include substantial amounts for making homes healthier over and above the direct investments in weatherization, ventilation, and electrification.

Total energy cost \$/year	\$1,757	\$2,572
Energy cost burden 50% FPL	16%	23%
Energy cost burden 100% FPL	8%	12%
Energy cost burden 150% FPL	5%	8%
Energy cost burden 200% FPL	4%	6%
Stranded Hydrocarbon Fuel Household, 2040 (See Chapter 4)		
Fossil fuel rate \$/MMBtu	\$70	\$40
Total energy cost \$/year	\$5,817	\$3,572
Energy cost burden 50% FPL	53%	33%
Energy cost burden 100% FPL	26%	16%
Energy cost burden 150% FPL	18%	11%
Energy cost burden 200% FPL	13%	8%

5.4 Interventions and Financial Policies to Reduce Bills

In addition to bill assistance, affordability can be improved by means of a variety of interventions that reduce home energy bills and, in many cases, provide co-benefits to health and comfort as described in **Chapter 3**. As discussed above in this chapter, a reasonable accounting of the non-energy co-benefits indicates that they may well be of the same order of magnitude as the investments, to the extent that the co-benefits can be even roughly quantified.

We investigate here the potential of four promising interventions to reduce energy cost burdens: weatherization, electrification, community solar, and demand response. For each intervention, we estimate the costs and bill impacts of the intervention for all homes. Currently, retrofits are free to eligible households—that is, those with income less than 200 percent of the federal poverty level or 80 percent of the area median income. Landlords are required to contribute 50 percent of the cost of major equipment like heat pumps.³⁶⁰ Weatherization, in the strict sense of improving the building envelope, proceeds as grants when the tenants are income-eligible.

³⁶⁰ Housing and Energy Programs, Energy Efficiency Program Operations Manual v.3, Department of Housing and Community Development, 2021, pp. 48-50, at <https://dhcd.maryland.gov/Residents/Documents/wap/EnergyEfficiencyProgramOperationsManualv.3-2021.pdf>

5.4.1 Weatherization

For decades, weatherization and improved efficiency have served as cost-effective methods to reduce energy bills. Weatherization most often entails sealing the envelope of a home through methods such as attic insulation while efficiency often entails maintenance and replacement of inefficient appliances so as to reduce energy consumption for the same energy services.

In **Chapter 1**, we noted that participation in weatherization is very low (**Figure 1-7**); on average only about one percent of eligible households have their homes weatherized each year. However, Maryland’s Department of Housing and Community Development is trying to ramp up weatherization and efficiency improvements rapidly.³⁶¹ The aim is to reach ~26,000 homes per year with a range of measures ranging from energy kits to full retrofits; the vast majority are not full retrofits. Therefore the ramp up involves both numbers of retrofits and their scope. This would be satisfactory, if achieved and if it covered the entire range of retrofits to be made, including electrification of fossil fuel-heated homes. Currently, fuel-switching retrofits are not permitted for low- and moderate-income households under Maryland’s EmPOWER efficiency program. Further, based on data as of November 2022, the actual achievement is falling considerably short of the ambitious target: the rate of retrofits in the first half of the program, though mid-2022, was only about one-fifth of the targeted rate of about 23,000 homes per year.³⁶² This may have been in part due to COVID-19 pandemic-related difficulties.

Historically, low participation in weatherization has a number of causes. The split incentive for rental property is chief among them. A substantial majority of low- and moderate-income households are renters and the vast majority of these units are individually metered so that the renters pay the utility bills. Landlords often do not allow access to their properties for the energy audits that are a necessary first step for weatherization measures to be implemented. Indeed, a pilot project in Baltimore found that “the landlord is a unique and major barrier [to weatherization] for renters,” and the refusal of permission to enter was the biggest problem: “Nearly half (46%) of all tenants who applied could not get permission for audit despite qualifying for weatherization otherwise.”³⁶³ More recently, the Department of Housing and

³⁶¹ The plan for the current 2021-2023 period is to reach almost 77,000 homes in all, compared to just 17,000 in the 2018-2020 period. 2021-2023 EmPOWER Maryland Program: Limited Income Program, Department of Housing and Community Development, August 31, 2020, p. 9.

³⁶² EmPOWER Maryland Limited Income Programs: Semi-Annual Report Q1Q2 2022, Department of Housing and Community Development, August 15, 2022, pdf p. 45

³⁶³ Green and Healthy Homes Initiative as quoted in Arjun Makhijani, Christina Mills, and Annie Makhijani, Energy Justice in Maryland’s Residential and Renewable Energy Sectors. Takoma Park Maryland: Institute for Energy and Environmental Research, 2015, p. 66 (emphasis in the original), at <https://ieer.org/wp/wp-content/uploads/2015/10/RenMD-EnergyJustice-Report-Oct2015.pdf>

Community Development, which administers the low- and moderate-income weatherization programs has noted that the vast majority—80 to 85 percent—of the applicants for assistance who indicate they want to participate in weatherization do not receive actual retrofits. This occurs “for various reasons—clients may become unresponsive or do not fully understand the value in energy efficiency programs, and many renters cannot gain landlord consent for participation.”³⁶⁴

The failure of rental housing to meet required building standards may be one reason for landlords to refuse access. When audits were conducted during the Baltimore City pilot, 88 percent of rental units that are subject to annual inspections passed the audit; for units that were not subject to such inspections, only 43 percent passed. In addition, the pilot project reported that many homes, both rental units and owner-occupied structures, were not up to building codes, with mold and bad roofs being among the common problems observed; wet basements were another frequent issue.³⁶⁵

Generally, the cost of maintaining properties in compliance with codes is borne by the property owner. In principle, therefore, it is not strictly a cost that should be attributed to the energy transition. However, weatherization and other major retrofits cannot be done unless issues of non-compliance with codes are addressed. In the case of rental units, this is an issue that relates to enforcement.

In the case of low- and moderate-income homeowners, the financial implications more directly impact the ability to carry out the retrofits needed as a part of the energy transition. For them, the financial implications of a holistic approach, such as that recommended by the Green and Healthy Homes Initiative, must be included in the cost of the transition. Those costs could be substantial. For instance, the following issues were discovered during the retrofitting of a detached residential structure in Baltimore:

- A leaking roof;
- Mold in the basement due to water leaks from a “defective air conditioning system”;
- Hot water heater pipe corrosion (which also created the risk of carbon monoxide); and
- A clothes dryer vent that was blocked, creating a fire hazard.

Fixing all these problems, making the home safer for an older person, and installing a new heating and cooling system cost a total of \$27,000. The cost of the entire retrofit was covered

³⁶⁴ Ibid. p. 12.

³⁶⁵ Green and Healthy Homes Initiative as quoted in Arjun Makhijani, Christina Mills, and Annie Makhijani, *Energy Justice in Maryland’s Residential and Renewable Energy Sectors*. Takoma Park Maryland: Institute for Energy and Environmental Research, 2015, p. 66 (emphasis in the original), at <https://ieer.org/wp/wp-content/uploads/2015/10/RenMD-EnergyJustice-Report-Oct2015.pdf>

by a federal grant to Green and Healthy Homes Initiative, a national organization, based in Baltimore City.³⁶⁶

Thus, in extreme cases such as this, it may take \$10,000 or more to bring the house up to the point where an energy-related retrofit in the narrow sense of that term could be reasonably done. We do not have an estimate of the total number of homes that will need retrofits for health and safety that are not directly related to weatherization and electrification.

The Department of Housing and Community Development recognizes the value of the whole house approach and implements it within the constraints of limited funding and the limitations of its mandate. For instance, DHCD weatherization funds can be used to resolve relatively minor problems of mold or moisture but more serious levels may result in a deferral or denial of the retrofit.³⁶⁷ The same approach, including for multi-family housing, is described in its 2021-2023 plan:³⁶⁸

The Department's core programs, Whole Home Efficiency and MEEHA [Maryland Energy Efficiency and Housing Affordability], continue the tradition of a whole-home approach, providing limited-income families with all cost-effective energy upgrades, limited health and safety measures, and incidental repair measures at no additional cost to them.

For the direct energy-related retrofits we have taken the following into account:

- The direct costs of retrofits (weatherization and heat pumps);
- Federal funds available for retrofits, particularly in reference to the rebates under the 2022 Inflation Reduction Act;
- Required landlord contributions;
- Incentives for landlords;
- Funds for a holistic approach to retrofits for income-eligible homeowners.

In order to account for health- and safety-related changes, we have added \$5,000 in grants to the cost of retrofits for half of the owner-occupied homes with income less than 200 percent

³⁶⁶ A description of the problems and the solutions is in Elizabeth Shwe, "Feds Direct Millions to Reduce Lead and Asthma Triggers in Low-Income Homes in Md.," Maryland Matters, January 24, 2022, at <https://www.marylandmatters.org/2022/01/24/feds-direct-millions-to-reduce-lead-and-asthma-triggers-in-low-income-homes-in-md/>

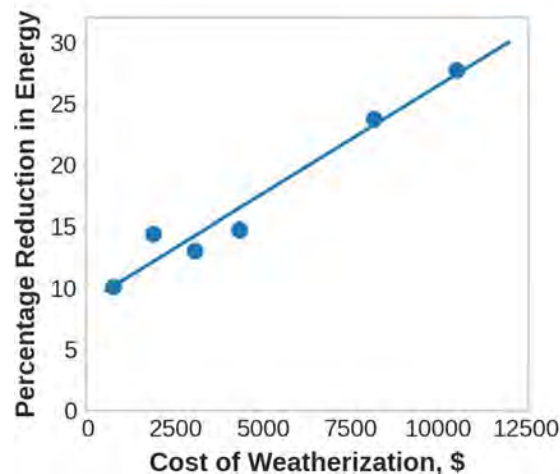
³⁶⁷ Housing and Energy Programs, Energy Efficiency Program Operations Manual v.3, Department of Housing and Community Development, 2021, p. 70, and pp. 72-73, at <https://dhcd.maryland.gov/Residents/Documents/wap/EnergyEfficiencyProgramOperationsManualv.3-2021.pdf>

³⁶⁸ 2021-2023 EmPOWER Maryland Program: Limited Income Program, Department of Housing and Community Development, August 31, 2020, p. 22.

of the federal poverty level. Not all homes will need healthy-home remediation and those that do may cost more than \$5,000 (as is often the case). As a reference point, the national average cost of mold removal is \$2,325.³⁶⁹

After the costs of remediation, we estimate the cost and energy savings of weatherization. Using data from a report tracking energy savings after intervention,³⁷⁰ we plot the percentage savings in 2021 dollars³⁷¹ for a given investment (blue dots in **Figure 5-3**). The costs of weatherization were roughly uniformly distributed from \$500 to \$10,000, so we use the same trend for the analysis presented here. The average amount of investment in weatherization is then \$5,250, which then becomes \$10,250 when combined with the healthy-home remediation costs. We then reduce their energy consumption by the corresponding percentage shown by the blue line.³⁷²

Figure 5-3: Reduction of energy use and cost of weatherization.



³⁶⁹ “How much will your mold removal cost?” Home Guide, at <https://homeguide.com/costs/mold-removal-cost> viewed on November 17, 2022.

³⁷⁰ Michael Blasnik, Greg Dalhoff, David Carroll, Ferit Ucar, Dan Bausch. Evaluation of the Weatherization Assistance Program During Program Years 2009-2011 (American Recovery and Reinvestment Act Period): Energy Impacts for Single-Family Homes 2009-2011, Oak Ridge National Laboratory, March 2015, at https://weatherization.ornl.gov/wp-content/uploads/pdf/WAPRecoveryActEvalFinalReports/ORNLTM-2014_582.pdf;

³⁷¹ All 2008 dollar values from the Blasnik et al. 2015 report adjusted to 2021 dollars using the core inflation index; data from the St. Louis Federal Reserve Bank at <https://fred.stlouisfed.org/series/PCEPILFE>

³⁷² Note that the y-intercept of the blue line is not zero, so we set a minimum spending of \$500. This captures the reduced efficiency gains for increased levels of spending.

5.4.2 Beneficial Electrification

Electrification using rates from the year 2021 nearly always decreases energy bills as discussed in **Chapter 2**. The recently-passed Inflation Reduction Act (IRA) provides substantial grants for electrifying most energy needs for low- and moderate-income (LMI) homes, as shown in **Table 5-5**. These IRA grants drastically change the cost-benefit analysis for electrification and, to a lesser extent, weatherization. In Maryland, since practically all homes with energy cost burdens greater than six percent have incomes less than 80 percent of the area median income, they are eligible for up to 100 percent of these conversion costs. While there exist smaller additional benefits available for both weatherization and electrification using more complicated mechanisms such as tax credits, we do not include those here. We can safely assume the following range of net costs for electrification, assuming a replacement at the end of lifetime for the respective appliance: \$1,000–\$5,000 for air source heat pump conversion depending on the current energy usage for space heating and retirement of either end-of-lifetime air conditioner, space heater or both; \$500–\$1,500 for hot water heater conversion depending on the current energy needs for water heating; \$6,500 set aside for electrical upgrades; and \$850 each for quality induction electric stoves or heat pump gas dryers without even considering replacement cost. We see that conversion is nearly entirely paid for in the majority of cases. For many homes that are retiring old furnaces, hot water heaters, stoves or dryers, electrification may in fact provide a net savings in the up-front investment cost since retirement of fossil fuel powered technologies will be nearly entirely paid for with IRA grants while a non-electric replacement would need to be paid for fully by the household. These negative net costs are not included in the estimated savings for this analysis. To estimate the impacts on energy usage, we use the same estimates for bill changes described in **Chapter 2**. With the introduction of the HEEHRA component of the IRA, recent increases in gas prices and their expected continued increase, and improvements in heat pump technology, we can now safely say that all homes with energy cost burdens greater than 6 percent will see immediate savings once electrified. This was not true for all LMI households as of just a few years ago.

Table 5-5: Grants for electrification in the Inflation Reduction Act.³⁷³

HEEHRA Rebate Levels For Qualified Electrification Projects	
Income Eligibility and % Costs Covered	
Low-income: <80% Area Median Income (AMI) % costs covered (including installation)	100%
Moderate-income: 80-150% AMI % costs covered (including installation)	50%
Overall Incentives	
Max consumer rebate	\$14,000
Max contractor rebate	\$500
Rebates for Qualified Electrification Projects	
Heat pump HVAC	\$8,000
Heat pump water heater	\$1,750
Electric stove/cooktop	\$840
Heat pump clothes dryer	\$840
Breaker box	\$4,000
Electric wiring	\$2,500
Weatherization insulation, air sealing, ventilation	\$1,600

5.4.3 Community Solar and Demand Response

We assume community solar provides a 20 percent discount on LMI household electric rates. After electrification, this rate reduction provides increased savings. We emphasize community solar because it is accessible for those who do not own their own rooftops and can be more cost effective than rooftop installations owned by the homeowner.

Given the importance of community solar in achieving lower costs, it is important to note some key points essential to achieving the necessary level of subscriptions:

- Maryland has a pilot community solar program of about 418 megawatts. Customers can acquire contracts for discounted electricity on a virtual net metering basis. The program was enacted by the General Assembly in 2015; it “...require[s] 30% of the solar capacity be assigned to LMI projects, with 10% of the total array energy to be used only for the Low Income participants”; moderate income for the purposes of community solar is defined as less than 80 percent of area median income; low-income is defined as less than 175 percent of the federal poverty level.³⁷⁴ While

³⁷³ Copied from <https://www.rewiringamerica.org/policy/high-efficiency-electric-home-rebate-act>

³⁷⁴ Maryland Energy Administration, “Community Solar for the LMI Community,” no date but circa 2020 inferred, at

125MW of the 418MW are reserved for projects that serve low- to moderate- income subscribers, the total number of low-income households served to date is believed to be in the hundreds (data has not been made public). This is because LMI project economics are not favorable to solar financiers and investors without proper incentives in place. Specifically, the risk profile of low- to moderate- income households with varying credit histories, combined with higher marketing and customer management costs, means that it is currently more expensive for community solar developers to serve low- and moderate-income households than non-low- and moderate-income households. Contract default backstops, provided by green banks or non-government organizations are one way to address this issue. Grants, added tax incentives and/or low-cost financing for projects serving low-income subscribers, such as those currently provided in small numbers by the Maryland Energy Administration and included in the Inflation Reduction Act, would also provide solar developers with the financial assurance needed to elect to sell to low- and moderate income subscribers. Such measures are necessary if community solar is to increase by the roughly two orders of magnitude needed to meet the requirements of needs of all low- and moderate-income households (by the expanded definition in the community solar program), once their space and water heating is electrified.³⁷⁵

- The usual guaranteed discount relative to residential rates (Standard Offer Service) is 10 percent. According to Lynn Heller, CEO of the Climate Access Fund, a statewide green bank that provides financing and bill payment default guarantees for low- and moderate-income community solar projects in Maryland, a discount of at least 20 percent is needed to make it worthwhile for low- and moderate-income subscribers to sign contracts, especially given that they currently need to pay two electricity bills—one to the community solar owner and one to the electric utility.³⁷⁶ The cost of this additional discount, combined with the added cost of recruiting low-income customers, makes it significantly more expensive for community solar developers to serve low- to moderate- (and especially low-) income customers. Without low-cost financing through green banks, investment tax credits like those included in the Inflation Reduction Act, and/or grant funding from the Maryland Energy

https://www.google.com/url?client=internal-element-cse&cx=007821330218074952993;n0vbm89nrde&q=https://energy.maryland.gov/residential/SiteAssets/Pages/CommunitySolarLMI-PPA/Community%2520Solar%2520for%2520the%2520LMI%2520Community.pdf&sa=U&ved=2ahUKewi6s-i0yL_7AhW0LFkFHc1xCP0QFnoECagQAO&u sg=AOvVaw15vpsovZkudGv-3cx7MD1L viewed on November 21, 2022

³⁷⁵ Assuming 11 MWh per year per household, 750,000 households, and 1,600 MWh/MW-dc solar generation, about 5,000 MW-dc capacity of community solar would be required.

³⁷⁶ This bullet point and the next three are based on Lynn Heller, CEO and Founder, Climate Access Fund, personal communication, November 7, 2022; cited with permission.

Administration, community solar projects will likely continue to serve predominantly non- low- to moderate- income households.

- Utility Consolidated Billing with Purchase of Receivables, which is available to all other third party suppliers, is not available to community solar providers. Under a Purchase of Receivable policy, the utility purchases the debt owed by the community solar subscriber to the owner of the solar by paying the owner the amount due. The amount due for the solar energy is consolidated with the amount due to the utility for the electricity it supplied, plus the connection charges. Thus the risk of contract default, now borne by the owner of the community solar project, is transferred to the utility, as is the case for all other third party suppliers where the utility (and hence ratepayers) assumes the risk for a small fee charged to the third party supplier.
- The Maryland Energy Administration provides two kinds of financial support for promoting low- and moderate-income household community solar subscriptions: a) grants to organizations such as the Climate Access Fund to enable them to provide solar developers with guarantees against contract default, and b) direct cash grants to solar developers who provide an additional discount to low- and moderate-income subscribers relative to utility residential rates.
- There are a number of creative models for increasing LMI households' participation in community solar. The Silver Spring, Maryland rooftop community solar promoted by Groundswell, a non-profit, provides one example. It is a 273-kW rooftop community solar project, known as Paddington Square. There are 63 regular subscriptions of 3 kW each, roughly at regular utility rates; they subsidize 28 low income households to get free subscriptions of 3 kW each. The project is underwritten by Montgomery County Green Bank.³⁷⁷
- The amount of the electricity bill directly impacts payment assistance in Maryland. Without Utility Consolidated Billing with Purchase of Receivables, the cost of community solar is not included in the utility electricity bills; as a result many LMI households are at risk of losing bill payment assistance, in whole or in part, deterring subscriptions.

We further assume demand response provides a \$150 reduction in annual energy bills.³⁷⁸

Demand response programs are a method to decrease the total generation capacity needed

³⁷⁷ Calculated from data at "Paddington Square Apartments in Silver Spring [Maryland]," Groundswell, at <https://groundswell.org/project/paddington/> viewed on November 23, 2022 and personal communication with Groundswell staff November 23, 2022 for generation per kW [written confirmation coming]

³⁷⁸ Inferred from Gerke, B.F., et. al. (2020). The California Demand Response Potential Study, Phase 3: Final Report on the Shift Resource through 2030. *Lawrence Berkeley National Laboratory*. Figure ES-3, pdf p. 21 and the range \$50 to \$100 per kilowatt-year (pdf p. 26), at https://eta-publications.lbl.gov/sites/default/files/ca_dr_potential_study_-_phase_3_-_shift_-_final_report.pdf

by minimizing peak electricity needs. Building enough available capacity for the highest demand hours is one of the greatest costs and challenges to providing reliable electricity. Demand response includes installing devices or thermostats to minimize electricity consumption for short periods of time when the demand across a utility is at its highest. For example, hot water heaters can be turned off for a few hours or smart thermostat temperatures shifted by a few degrees with minimal inconvenience to customers. Demand response programs have been available³⁷⁹ in Maryland and should be expanded, especially for low-income households. Demand response payments should be in the form of utility bill credits so that there is a direct impact on reduction of energy cost burdens.

Moreover, when demand response programs have high enough participation, they can offset the need for utilities to rely on costly generation sources that are only needed for a small fraction of the time—such as peaker power plants—and thus can pass these savings into rates, decreasing energy bills for all.

5.4.4 Proposed Suite of Grants

To ensure that integration of LMI households with the energy transition is affordable, the retrofits themselves must be affordable. Current policy is appropriate in that regard; the main issue is that the pace of retrofits and the depth of most of them must both be intensified.

As discussed in **Chapter 1**, retrofits, including deep retrofits, are available to income-eligible homeowners at no cost to them—that is, the entire cost of the retrofit is a grant. Various sources of funds are used for these grants, which are made in most cases by the Department of Housing and Community Development and also by the Maryland Energy Administration. In the case of rental housing, landlords are required to put up half the cost of major appliances like heat pumps, air conditioners, or refrigerators. Our proposals are to:

- Retain the present basic approach for retrofits, including the DHCD income-eligibility level;
- Provide an additional incentive to landlords; and
- Expand the income eligibility of bill payment assistance to be the same as for DHCD weatherization: 200 percent of the federal poverty level or 80 percent of the area median income, whichever is greater.

Any costs not covered by grants can be effectively added to energy bills in the form of loans or from other sources, notably from the federal government's Inflation Reduction Act.

³⁷⁹ https://www.bge.com/MyAccount/MyBillUsage/Documents/Electric/Rdr_15.pdf

An essential condition for success is that the capacity of the implementing agencies, mainly DHCD but also the Maryland Energy Administration, will need to be strengthened to enable an effective expansion of the retrofit programs.

5.4.5 Bill Impacts from Home Interventions

When implemented sequentially, the four above interventions with proposed financing can drastically reduce energy bills as shown in **Figure 5-4**. The topmost box and whisker plots represent the current distributions of energy cost burdens within each income bracket. The shaded portion—the box—represents households in the middle 50 percent of the energy cost burdens; 25 percent have values above the top of the box and 25 percent have burdens below the lowest value shown for the box. Proceeding to the right for each income group, we see how each sequential intervention applied to all households impacts these distributions. Weatherization includes both financed payments for weatherization using 15-year loans and reduced energy use for heating and cooling, with the associated bill reductions. Weatherization will typically pay for itself for most homes over a 15-year period with benefits that will persist for many more years after. Households with incomes below the federal poverty level see the greatest reduction in energy costs due to the proposed grants discussed above. After weatherization, homes are electrified. At this point, all energy is electric. Next, through use of discounted community solar programs, and then demand response, we see further reductions of energy cost burdens. At this point, the majority of homes with incomes above the federal poverty level have energy cost burdens below the six percent affordability threshold, but roughly three fourths of households earning below the federal poverty level are still cost-burdened. We further investigate how the affordability gap would change as the interventions are applied to each home in **Figure 5-5**.

Figure 5-4: Box and whisker plot showing impact of various measures by income group.

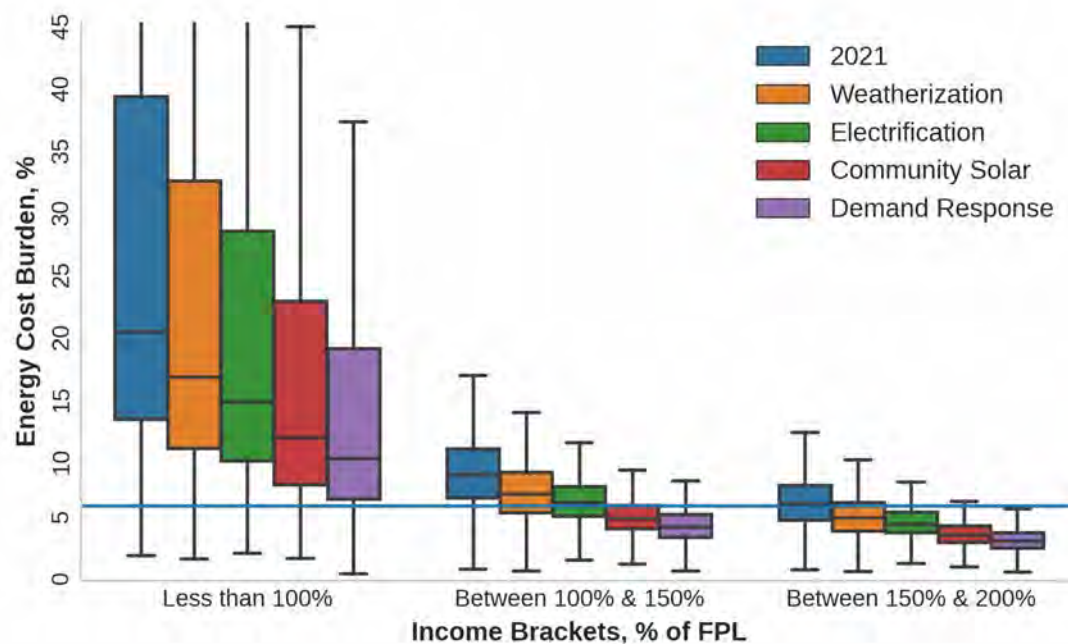
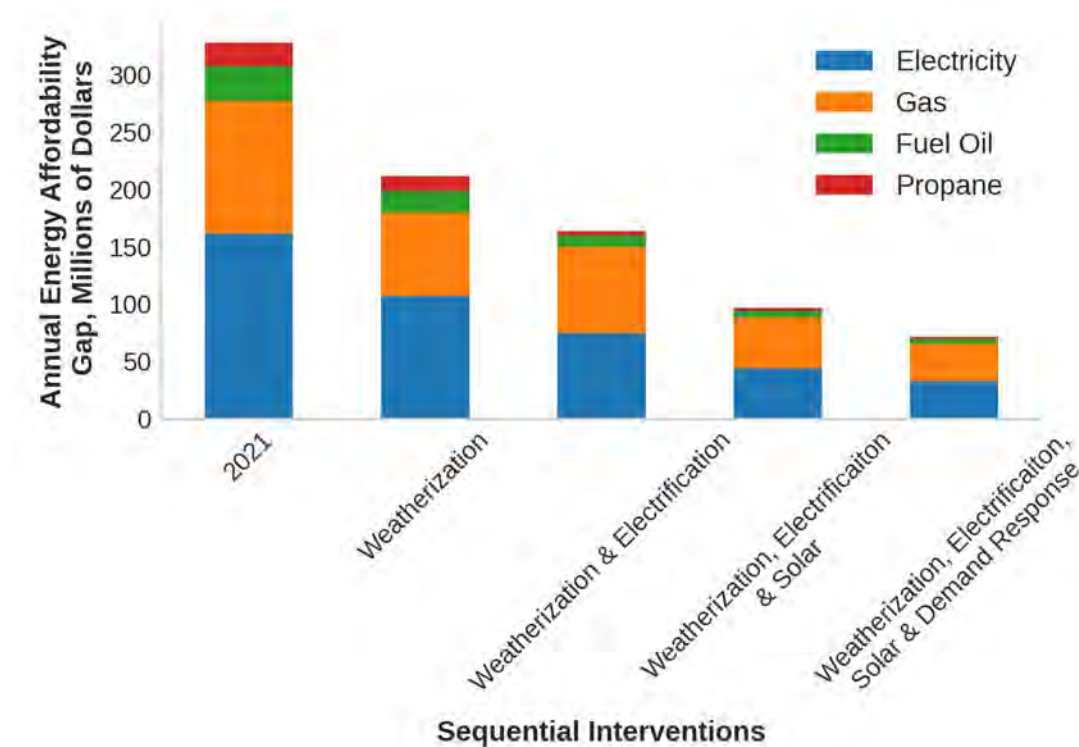


Figure 5-5: Reduction in the affordability gap with sequential measure implementation.

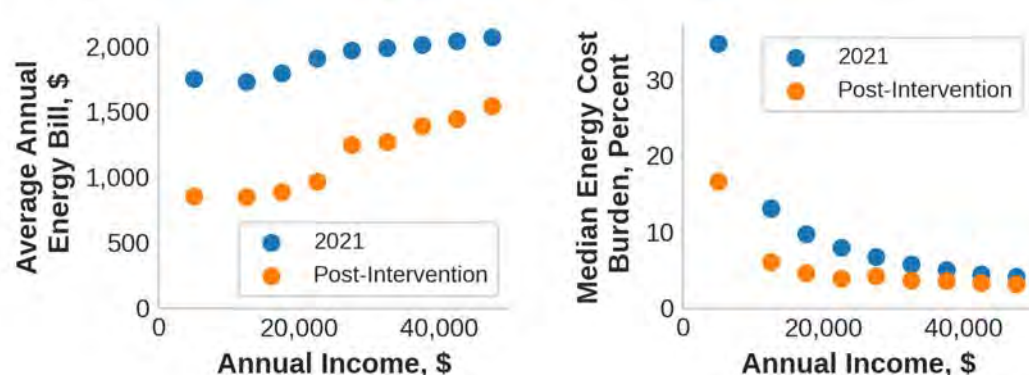


The box and whisker plot and the bar chart (**Figures 5-4** and **5-5** above) show that electrification coupled with discounted community solar provide the most significant reductions in the need for assistance funds by systemically reducing energy bills. Weatherization (including ensuring healthy retrofits) creates the foundation on which electrification takes place.

Energy cost burdens, though lower with the above measures, will tend to remain high for most of the 100,000 households whose annual income is less than \$10,000. We see in **Figure 5-6** both energy cost burdens and annual spending as a function of annual income. The figure only shows the cost to the household, and does not include grant amounts, which are included in **Figure 5-8** below showing the overall picture as it would evolve over time. We see that the lowest-income households use the least energy, as expected since they live in smaller homes. Using the proposed suite of interventions, mean energy bills for the lowest incomes were reduced drastically from \$1,750 to \$700. The greater proportional decrease in energy bills for lower income households arises due to an increased reliance on resistive electric space heating and other more costly fuels for space heating among the lowest-income

households. This decrease in energy bills results in a correspondingly drastic decrease in median energy cost burden from 35 percent to 14 percent, but still far from the target value of six percent. In other words, full integration into the energy transition would make energy bills affordable by themselves, without the need for assistance except for the lowest income households. But with an income at 20 percent to 30 percent of the federal poverty level, it is difficult to imagine how energy-related measures alone could accomplish the energy affordability goal. Only an increase in income can do that. There is a range of approaches to increasing income, from guaranteeing families a minimum income to increasing the minimum wage to providing child care, for instance, to enable the family to increase their income-earning hours. These broad issues, while critical, are beyond the scope of the present report.

Figure 5-6: Impact of combined measures on energy bills and energy cost burden as a function of income.



Under the proposed scenario above, households will experience different degrees of benefits depending on where they are geographically. As discussed before, this is dependent on climate, which determines the amount of energy used for heating and cooling, fuel types used, local fuel prices, type of home, and incomes. We map the impact on median energy cost burden geographically to portray the cumulative effects of the proposed scenario in **Figure 5-7**. We see the greatest changes in cost burdens arise in neighborhoods with high numbers of low-income households in Baltimore and along the Eastern Shore.

Figure 5-7: Geographical variation in impact of combined measures on energy cost burden.



5.4.6 Financial Implications Over Time

Implementation of these interventions can begin to provide net savings over a bill assistance approach. Specifically, in **Figure 5-8** we imagine a scenario over a 15-year time period after which all LMI homes have been provided the interventions described above with the households with the highest energy cost burdens prioritized first and equal numbers of homes are implemented each year. In **Figure 5-8(a)**, the black dotted line assumes business as usual, with a constant energy affordability gap being filled by the amount indicated by the line (\$360 million per year).³⁸⁰ The gray shaded area represents the amount of bill assistance under the proposed set of policies. It also starts at \$360 million per year but decreases to \$80 million per year by the end of the 15-year period, which is \$40 million less than the \$120 million per year currently available. The solid black line assumes the current affordability gap plus the proposed total additional grants for all households eligible for assistance until 2038 under our recommendation for expanding eligibility. By 2038, the energy cost burden of the vast majority of households with incomes above 100 percent of federal poverty level will have been reduced to below six percent, often well below that level (see **Figure 5-4** above). At that point the basic investments in healthier homes, electrification infrastructure, building envelope improvements, and landlord incentives to enable them will have been made. Some weatherization funds will be needed to replace the heat pumps after their 15-year estimated life for those with energy cost burdens still above six percent. We estimate this amount to be

³⁸⁰ For the purpose of these calculations we assume a constant affordability gap; this implicitly means a constant number of households helped and constant energy costs. In practice, changes in income, housing standards for new housing, changes in the cost of renewable energy, and changes in utility rates will affect the affordability gap—in both directions. The estimates derived from this exercise are approximate, but satisfactory for setting policy directions and determining the magnitude of resources needed to meet a universal affordability criterion.

just above \$20 million a year—or almost \$30 million less than currently available state and federal weatherization funds (excluding the Inflation Reduction Act.) **Figure 5-8(a)** shows the purposes for which the funds would be used; **Figure 5-8(b)** shows the sources of the funds, including new funds that Maryland will have to raise until 2038 to meet the goal of universal energy affordability and universal integration into the energy transition. The solid black line in **Figure 5-8(b)** shows existing resources available at \$170 million per year: \$120 million for assistance and \$50 million for weatherization (**Chapter 1**). The amount needed for both in 2039 and after will however be about \$100 million per year (rounded), for an annual savings of \$70 million relative to 2021 outlays.

Figure 5-8 (a): Uses of funds for universal affordability and energy transition integration and **(b)** potential sources of funds for achieving that goal.

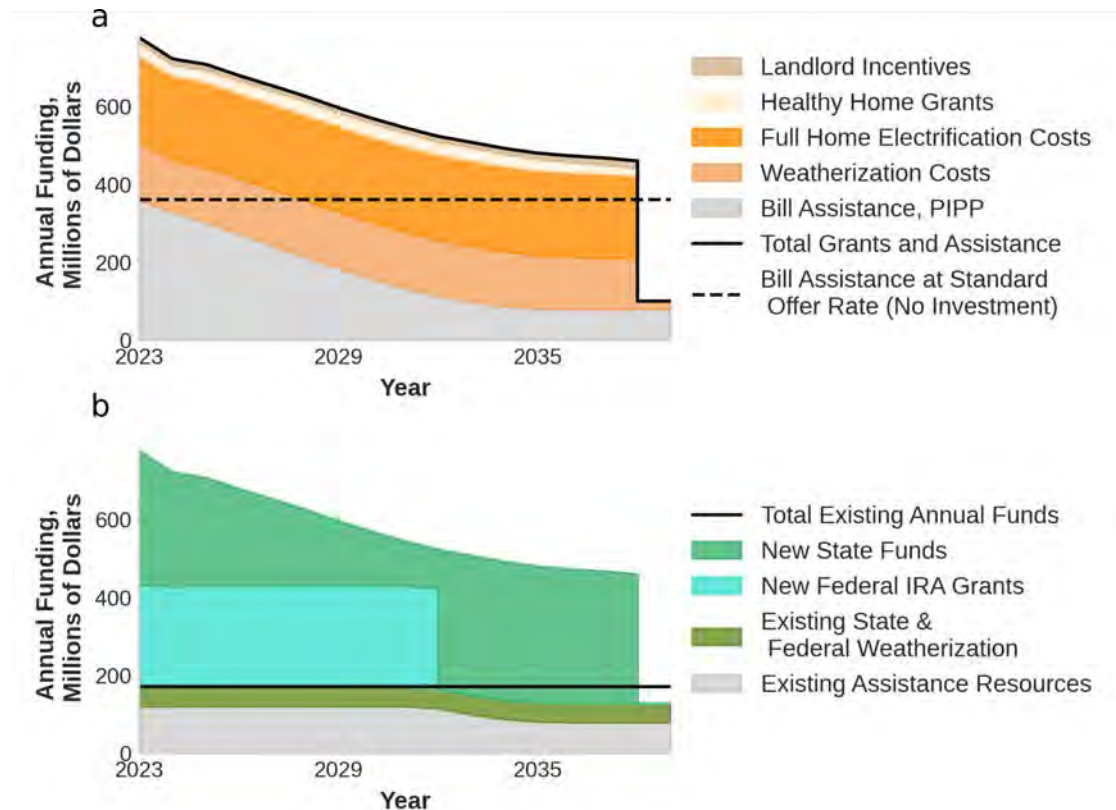


Figure 5-8 above shows the total funds that would be required to maintain universal affordability in a heuristic manner, positing full affordability in the very first year. The dashed straight line shows the funds needed for universal PIPP enrollment only, assuming no adoption of clean energy technologies. The solid black line shows the funds required if PIPP is

combined with clean energy investments. The latter approach is compatible with the Climate Solutions Now Act; it is also much lower in cumulative cost to Marylanders. The cumulative cost for an assistance-only mode over 15 years would be \$5.4 billion; cumulative funds needed, excluding Inflation Reduction Act funds, over the same period would be about \$4.3 billion. Even more important, the need for \$360 million in assistance funds would continue indefinitely after 2038. In contrast, after the investments are made, the total funds needed for universal affordability will be about \$80 million per year, or \$90 million less than currently available assistance and weatherization funds.

A present value calculation with a three percent discount rate out to the 2100 yields the following results:

- The present value of the cost of an assistance only approach to affordability is about \$10.8 billion.
- The net present value of the cost of the assistance plus integration approach is about \$3.1 billion. This takes into account the savings in assistance, relative to present resources, from 2039 to 2100, amounting to about \$1.2 billion and the \$4.3 billion present value of new state funds from 2023 to 2038. Compared to assistance alone, the net savings of pursuing an equitable clean energy transition would be almost \$8 billion out (rounded) to the year 2100 (where climate calculations usually stop).³⁸¹

The initial costs are higher because there are retrofit grants in addition to PIPP expenses. But the retrofits reduce bills and total costs decline over time. To recapitulate, the following elements have gone into the calculation of the annual funds needed to make energy bills affordable for all-low and moderate-income households, up to 200 percent of the federal poverty level:

- Bill assistance funds needed to fill the affordability gap between energy bills and six percent of household income;
- Grants for weatherization of all households;
- Grants for electrification of space and water heating using efficient heat pumps for all households, including funds available from the Inflation Reduction Act;³⁸²

³⁸¹ The net present value of \$8 billion for cumulative savings is sensitive to the discount rate. We have used the usual social discount rate of 3 percent in constant 2021 dollars. Using a zero percent discount rate (i.e. costs and savings are not discounted), the savings to the year 2100 rise to \$28 billion. A five percent real discount rate reduces the savings to \$3.3 billion, still very substantial. The savings stay positive till a real discount rate of almost 9 percent—a rate never used in such calculations when there are substantial long-term social and environmental benefits involved.

³⁸² Under present policy, landlords would be required to contribute 50 percent of the funds for major equipment like heat pumps. Essentially all of this amount would be covered by the Inflation Reduction Act.

- Community solar subscriptions at a 20 percent discount relative to utility rates, starting at the time when retrofits, including electrification investments, are completed;
- \$150 per year electricity bill reduction due to demand response participation.³⁸³

Sources of Funds

Figure 5-8(b) shows that the funds required over the 15 years during which all LMI households are fully integrated to the energy transition will require funds well above the \$170 million a year available for assistance and weatherization 2021. A substantial portion of the additional funds, including for electrification of space and water heating and cooking (where fossil fuels are now used) will come from grants, rebates, and tax incentives contained in the 2022 Inflation Reduction Act. However, ensuring affordability for all will also require the institution of a Percentage of Income Payment Program with universal enrollment that is not covered by any new federal legislation. Substantial funds over those available for making homes healthy and to incentivize landlords participation are also likely to be needed. Thus significant new state-generated funds will also be needed.

The need for state funds will vary over time. Until 2032, the Inflation Reduction Act could fund almost the entire electrification effort, including the landlord's 50 percent share now required for major equipment, and also assist with weatherization. The need for PIPP funds will decline over time, since weatherization, electrification, community solar, and demand response will reduce bills in most cases below six percent of income thus eliminating the need for assistance funds for those households. After 2032, state funds will be needed to replace Inflation Reduction Act funds until 2038 (assuming IRA is not extended), as can be seen in **Figure 5-8(b)**, at which point all LMI homes would be retrofitted in this scenario. After 2038 the needed funds would decline sharply to remaining assistance for households with energy cost burdens still above six percent and heat pump replacement costs for the same households. There will actually be an estimated savings of \$90 million a year in savings from 2039 onwards relative to funds available in 2021 for assistance and weatherization. **Figure 5-9** shows how the need for state funds will vary over time.

Figure 5-9: Variation of new state funds needed for PIPP and other energy transition efforts (assuming the Inflation Reduction Act is not extended beyond 2032); there is a surplus in 2039 and thereafter.

³⁸³ Demand response participation across numerous appliances will require broadband availability. The cost of broadband has not been included because the need and utility of universal broadband is general and goes far beyond the issue of demand response participation. We assume smart appliances will become the norm and will therefore also be installed in LMI housing.

It may be difficult to raise the funds that would be needed to match these expenses via an annual tax, such as on income, CO₂ emissions, or gasoline. The funding requirements will vary a great deal from year to year, and may depend on future allocations of funding from the federal government. Another option would be a graduated tax, but this would also have to vary if federal funding is discontinuous. For instance, a tax of the highest earning five percent of Marylanders would start at about 0.6 percent in 2023, decline to 0.2 percent in 2032, rise to 0.6 percent again from 2033 to 2038 and then go to zero in 2039. Taxes on fossil fuels or CO₂ would gyrate similarly. Another option would be a one-time wealth tax is an option that would raise all the necessary funds in the very first year and go to zero thereafter. A one-year tax of about 1 percent on the wealthiest 0.1 percent of Maryland households would raise the needed \$3 billion.³⁸⁴ The tax could automatically go to zero in the second year and stay zero.

The above assessment only covers the direct costs on a business-as-usual basis without considering the Climate Solutions Now Act of 2022, health costs, and non-energy benefits such as reduced illness and greater housing stability—that is the factors that were explored in detail in **Chapter 3** (health) and **Chapter 4** (fossil fuels and the energy transition). We now examine these issues from a policy point of view.

Indoor Air Pollution

Combustion of fossil fuels and wood for space, water heating, cooking creates contributes to poor indoor air quality. As discussed in **Chapter 3**, it is well established that residential combustion-based appliances are a source of indoor CO, NO₂, PM_{2.5}, and VOCs, including formaldehyde and benzene. Indoor air pollutant concentrations associated with combustion appliance leaks and emissions can reach levels that exceed health-based guidance values—even when the appliances are not being used. Exposure to these pollutants is associated with a variety of adverse cardiovascular and respiratory health effects, particularly for those with underlying health conditions (e.g., asthma).

When such health burdens are not considered, natural gas is often the lowest-cost fuel for space and water heating; most such households also cook with natural gas. Low-income households and renters are more likely to lack range hoods for their stoves. In some cases, gas

³⁸⁴ This assumes that the balance of the fund, i.e., after deducting each year's expenses for PIPP and the investments in the transition, will earn five percent per year. We estimate the 2021 wealth of the top 0.1 percent of Maryland households at about \$300 billion. This estimate was derived from Isabel Sawhill and Christopher Pulliam, Six Facts about Wealth in the United States, Brookings Institution, June 25, 2019, at <https://www.brookings.edu/blog/up-front/2019/06/25/six-facts-about-wealth-in-the-united-states/>, Todd Burnaford, What is the Average Net Worth by State, Personal Capital, June 15, 2021, at <https://www.personalcapital.com/blog/family-life/what-is-the-average-net-worth-by-state/> and Emmanuel Saez and Gabriel Zucman, Letter to Senator Elizabeth Warren, January 18, 2019, at <https://www.warren.senate.gov/imo/media/doc/saez-zucman-wealthtax.pdf>

stoves are used for space heating, which increases indoor air pollution. As discussed in **Chapter 3**, indoor levels of NO₂ are often at levels that are associated with statistically significant increases of a variety of respiratory symptoms in children. (See the box on Baltimore-specific studies in **Chapter 3**.) Despite the relatively low cost of natural gas, the very same areas also tend to have high energy cost burdens (**Figure 2-4, Chapter 2**); these same areas also have higher concentrations of Black populations in Baltimore and higher prevalence of asthma (**Figure 3-2**).

The health costs of natural gas use have not yet been integrated into either regulatory or legislative perspectives. Unless they are factored in, natural gas provides the illusion of being cheaper in dollar terms while negatively impacting the health of large numbers of Marylanders, causing added expenditures and distress to them, with a disproportionate impact on BIPOC communities and low-income households. Of course, the increase in medical expenses occasioned by natural gas-related medical expenditures would exacerbate the frequently noted financial stresses between paying utility bills and rent or buying food and medicine. There are also impacts on non-low-income households, for instance in the form of costs of increased emergency room visits and an increased need for utility bill payment assistance.

Electrification is an obvious, if incomplete, solution to these public health challenges. In the prior section, we have shown that energy cost burdens can be greatly reduced when weatherization, electrification, and community solar supply are combined. There are advantages to implementing changes as a package. For instance, weatherization alone can reduce ventilation and/or change its patterns in a home, which can adversely impact indoor air quality, as discussed in **Chapter 3**. The replacement of a gas stove with an induction stove can reduce fossil fuel-related emissions, but cooking still produces air pollutants such as particulate matter and ventilation—such as a fume hood—is likely still necessary. As a result, it is essential to evaluate whether and how much additional mechanical ventilation is needed to maintain or improve ventilation when homes are weatherized. Measurement of post-retrofit air quality as well as energy cost burdens must become a routine part of retrofits and improvement of quality of life. A holistic approach to retrofitting buildings is needed to join climate, economic, and public health goals. From a health and efficiency point of view, it is best if weatherization, ventilation, health hazard remediation, and electrification of space and water heating and cooking were carried out in a single major retrofit.

Natural Gas Rates and Energy Burdens

While natural gas is a relatively low-cost fuel today, it will likely not stay that way in Maryland. We showed in **Chapter 4** that, absent policy action, natural gas rates will begin to rise steeply

in the 2030s due in part to the 2013 STRIDE law allowing pipe replacements and the addition of the investment cost to the rate base post facto. The Climate Solutions Now Act and the imperative of reducing natural gas use will likely drive electrification; those who can afford it will electrify, leaving the remaining ratepayers, including lower-income households, stuck with paying for the entire natural gas distribution infrastructure. By 2040, the natural gas rates would more than triple to roughly \$40 per MMBTU compared to \$12 or so in 2021. Thus, while natural gas is at least nominally an economical fuel today, it will not remain so.

Proposals to maintain the natural gas infrastructure and putting synthetic methane and biogas in it will make matters worse. As discussed in **Chapter 4**, the cost of commodity gas would increase many fold from under \$10 per MMBTU to the range of \$30 to \$70 MMBTU. Even if it is used as a supplement to heat pump electric heating (the supposedly lower cost option), heating bills would increase significantly. The drawbacks of a mixed electrification with a gas supplement are discussed in **Chapter 4**; suffice it to say here that even the E3 study that suggests it as the lowest cost option estimates that heating bills would go up by several tens of dollars a month as compared to an all-electric option.³⁸⁵ As a result, energy costs and the need for assistance would rise by tens of millions of dollars a year—a consideration that was not taken into account.

Minimizing stranded costs also will require minimizing natural gas connections to new buildings, whether residential or commercial.

Finally, the negative health impacts of indoor air pollution from use of gas as a fuel would remain; so would the climate impacts from methane leaks.

5.5 Conclusions

Making energy affordable for all Marylanders as part of the energy transition is a necessary element of economic and environmental justice. It should be unacceptable that there are hundreds of thousands of Maryland families with very high energy cost burdens that routinely impose impossible choices on low- and moderate-income families. Pay the rent or the electric bill? Buy medicines or pay the natural gas bill? Buy food and risk an electricity shut-off or pay the bill and go hungry? These privations also impact non-low income households and the state's society at large; the quantifiable costs alone are very large and of the same order of magnitude as the additional resources it would take to reduce energy cost burdens universally to six percent or less.

³⁸⁵ Tory Clark, Dan Aas, Charles Li, John de Villier, Michaela Levine, and Jared Landsman, Maryland Building Decarbonization Study: Final Report, Energy + Environmental Economics, October 2021, slide 35 at https://mde.maryland.gov/programs/Air/ClimateChange/MCCC/Documents/MWG_Buildings%20Ad%20Hoc%20Group/E3%20Maryland%20Building%20Decarbonization%20Study%20-%20Final%20Report.pdf

Maryland's Climate Solutions Now Act presents a huge opportunity to do affordability well. A full integration of low- and moderate-income households into the energy transition with high priority would reduce assistance requirements while keeping their energy cost burdens low and allowing them to participate in the transformation of the state's energy sector. Eliminating fossil fuels will also improve both indoor and outdoor air quality—and hence health—on average. But specific attention needs to be paid to the disadvantaged and more vulnerable demographic groups to ensure that they are included—without that inclusion, matters could deteriorate for them even as things improve on average. This inclusion means not only ensuring that these populations receive the benefits of the clean energy transition, but also that there are mechanisms (e.g. funding, outreach efforts) to enable historically excluded populations to participate in the process of designing, implementing, and evaluating the relevant policies and programs.

The challenges are as daunting as the prize is attractive. The pace of weatherization and electrification of low- and moderate-income homes will have to increase by five to ten times compared to recent years. A much better, more inclusive infrastructure for assistance application and provision that respects the dignity of low- and moderate-income households will need to be put into place. Much of the effort now spent on verifying documentation will need to be shifted to outreach and enrollment of households into a program such as a PIPP. A coordinated holistic approach will be needed. That means more resources. While the amount of assistance needed in the long term will be the same order of magnitude as currently available resources, about \$300 million a year in additional resources will be needed in the initial years. This includes grants for a holistic approach to retrofits and incentives for landlords, and weatherization grants for all households below the federal poverty level.

Findings

1. **The highest cost burdens tend to be in the lowest income areas—and are geographically concentrated in Baltimore City, which is also majority Black, and in rural areas in Western Maryland and the Eastern Shore (Chapter 2).**
2. Maryland's energy assistance programs are effective in reducing energy costs burdens, but these burdens remain high for many assistance recipients.
3. The largest problem with the assistance programs is that they do not reach the vast majority of recipients for a complex set of causes:
 - a. The application process is complex, replete with obstacles, and literally punitive in its tone;
 - b. The types and extent of documentation required—such as social security numbers and citizenship status of every household member—presents barriers to application for large numbers of families;

- c. The extent of proof required is onerous: twenty-seven different types of income must be documented for each earning member; a sworn attestation is even required for household members with zero income.
 - d. Maryland's decentralized administration of assistance programs has the advantage of being community-centered, but its implementation lacks uniform standards, resulting in varying rates of denial. Given the documentation and verification requirements it is also costly and cumbersome.
- 4. Self-attestation of income has been shown to be a success not only in California, but in Baltimore City, where random audits have not found even a single instance of a fraudulent income declaration in applications for retrofit programs carried out by the non-profit Civic Works.
- 5. Since Maryland has combined the application process for a variety of different benefits, including energy bill payment assistance, eliminating documentation requirements could benefit several state and local assistance programs. In any case, up-front documentation requirements should be eliminated in favor of self-attestation, and the amount of information required should be reduced and made comparable to the minimal approach in California.
- 6. A simpler application process, used in some other states like California and Oregon, would go a long way in increasing participation. For instance, California requires no documentation up front, no names other than those of the applicant, and no social security numbers. This will require separation of federal heating program assistance (LIHEAP) from state assistance funds. However, LIHEAP can be disbursed via the new MDThink application process that combines applications for a variety of programs that include federal monies.
- 7. A PIPP with near universal enrollment and eligibility up to 200 percent of the federal poverty level would require about \$200 million per year in funds above those currently available. These funding needs would decrease over time, however, as bill-saving investments in weatherization and electrification begin to bear fruit.
- 8. A variety of sources of revenue with zero or low impact on the vast majority of Marylanders are available to meet the funding requirements of a PIPP with universal enrollment and retrofit grants.
- 9. High rates for electricity and gas charged by third party suppliers would increase the assistance requirements by tens of millions of dollars each year.
- 10. The quantifiable non-energy benefits to non-low-income households will be very large. Data are not available to enable precise estimates of statewide positive non-energy benefits but they may well be of magnitude comparable to the added cost, even if one counted only the benefits to non-low-income households.

11. Combustion of fossil fuels and wood in cooking and heating appliances contribute to poor indoor air quality, particularly when the appliances are not vented outdoors. Furthermore, gas-based appliances can leak when not in use and can contribute to hazardous air pollutant concentrations indoors. Appliances reliant on electricity do not require indoor combustion and therefore do not emit combustion-related emissions indoors. However, the use of electric or induction ranges and ovens may still contribute to indoor air pollutant emissions related to types of foods being cooked.
12. Energy efficiency retrofits focused on weatherization without ventilation may contribute to poor indoor air quality. Combinations of weatherization and ventilation retrofits, electrification programs, and educational programs are more likely to provide simultaneous energy efficiency and indoor air quality benefits.
13. The amount of assistance required to make energy cost burdens affordable will increase significantly if current policies allowing expansion of gas infrastructure and replacement of existing infrastructure are allowed to continue.
14. Virtually net-metered discounted community solar electricity is one of the keys to reducing energy assistance requirements, all the more so once space and water heating have been electrified. It is also an essential aspect of harmonizing equity goals with the greenhouse gas emission reduction targets of the Climate Solutions Now Act.
15. Current regulations do not permit community solar developers and subscribers the benefit of Purchase of Receivables, by which the utility purchases the debt owed by the solar subscriber to the developer, enabling a single consolidated electricity bill to be sent to the subscriber. Many low- and moderate-income subscribers risk the loss of electricity bill payment assistance because their full energy usage is not seen by the utility.
16. The added funds required for a PIPP would decline steadily if low- and moderate-income households are fully integrated into the energy transition required by the Climate Solutions Now Act. Full integration includes weatherization (including of rental properties), conversion of fossil fuel space and water heating to efficient electric heat pumps, provision of community solar electricity at a significant discount (20 percent or more) relative to residential utility rates, and enabling all households to effectively participate in demand response programs. A holistic “green and healthy homes” approach is needed for energy retrofits to result in economic and health benefits—and, in many cases, for energy retrofits to be implemented at all. The detailed estimates made in this report indicate that:
 - a. The energy cost burdens of the vast majority of low- and moderate-income households can be reduced below the six percent affordability threshold by

integration in the energy transition; these households would therefore no longer require assistance for paying their energy bills.

- b. Assistance would still be needed for 60 percent of households earning incomes less than the federal poverty level, but the total amount of assistance needed for these households with the lowest incomes would be about \$40 million less than the assistance resources available in 2021.
17. The pace of weatherization and retrofits of low- and moderate-income homes would need to be increased by five to ten times to protect low-income households from the impact of rising natural gas rates; efficient, complete electrification is essential to achieving this goal. Partial electrification that leaves gas infrastructure in place will increase energy cost burdens and deprive households of the full health benefits of electrification.
18. The greatest benefits of interventions aimed at improving indoor air quality and health will be derived when targeted programs are implemented carefully and focus on populations vulnerable to poor indoor air quality, such as children, pregnant people, and those with preexisting cardiovascular and respiratory disease.
19. The lack of Purchase of Receivables for community solar subscriptions is a significant hindrance to getting low- and moderate-income subscribers, since without it they must pay two bills. Some of them may also be at risk of losing electricity bill payment assistance money, since such assistance is only provided in consideration of the electricity bills, which, without Purchase of Receivables, are reduced by the full amount of payment due to the solar developer.
20. Maryland passed a law in 2021 requiring the Public Service Commission to take climate impacts into account in its regulatory actions. If vigorously applied, this could be a powerful instrument in achieving the ambitious targets of the 2022 Climate Solutions Now Act: 60 percent greenhouse gas emission reductions by 2031 and net zero emissions by 2045.

Recommendations

1. It is essential to put in place a bill assistance program such as a Percentage of Income Payment Plan that has near-universal enrollment to make energy cost burdens affordable for all Marylanders. This will require significant additional funding in the near term but not in the long term if coupled with clean energy investments.
2. A thorough simplification of the application process that respects the dignity of low-income households is urgent and an essential foundation of affordability. It should be based on self-attestation—that is, *up-front documentation requirements should be eliminated*. Near universal enrollment within three years should be the goal.

3. There are varied income eligibility criteria from different segments of the low- and moderate-income population, with 175 percent of the federal poverty level being the requirement for most households. This leaves tens of thousands of households with energy cost burdens more than six percent. Further, the DHCD weatherization program, which gets most of its referrals from the assistance program, is available to households with up to 200 percent of the federal poverty level or 80 percent of the area median income, whichever is higher. The eligibility requirement should be made uniform and set at the DHCD weatherization level.
4. Third party supply of electricity or natural gas to any household eligible for bill payment assistance at rates above Standard Offer Service should be prohibited, extending the prohibition from only those who actually get assistance to all customers.³⁸⁶
5. A vigorous program of retrofitting all low- and moderate-income households should be implemented with the pace increasing roughly ten times above the rate in the last decade.
6. Priority in retrofits should be given to those areas where relatively large proportions of the population have high energy cost burdens or high risk of indoor air pollution. These areas are mainly on the Eastern Shore, in Baltimore City, Western Maryland, and certain parts of Southern Maryland. Priority to these areas would reduce environmental injustice—Baltimore City is majority Black and has much lower income on average than the rest of Maryland (see Baltimore City maps in **Chapters 2 and 3**). Early electrification and healthy home retrofits in these areas may also provide health benefits, since these are also the areas with high asthma prevalence (**Figure 3-2**).
7. In its 2021 Annual Report, the Maryland Commission on Climate Change made a number of recommendations that are especially pertinent to equity in the energy transition, including retrofitting “100% of low-income households by 2030,” encouraging fuel switching away from fossil fuels, mandating that 95 percent of residential heating system sales should be heat pumps by 2030, incentives for all-electric buildings, specifically including “incentives for net zero energy all-electric new buildings”.³⁸⁷ These recommendations were made before the Climate Solutions

³⁸⁶ “Standard Offer Service” is the rate for commodity electricity or natural gas supply acquired by regulated utilities on wholesale markets for resale to retail customers within Maryland. This rate changes periodically since Maryland’s commodity electricity and natural gas supply are acquired on wholesale interstate markets under the supervision of the Public Service Commission. As of 2022, state law only prohibits above SOS third party rates for low- and moderate-income households that get assistance, leaving the vast majority still vulnerable to unnecessarily high bills.

³⁸⁷ Maryland Commission on Climate Change, 2021 Annual Report, Maryland Department of the Environment, 2021, p. 8, at

Now Act of 2022—and hence before the large potential impact of the law on natural gas costs could be estimated. The following recommendations, applicable to the residential sector, are consonant with the spirit of the 2021 Climate Commission recommendations, but made more stringent in light of the needs and exigencies of the Climate Solutions Now Act of 2022 (see **Chapter 4** in particular for details on impacts):

- a. Weatherize, electrify with efficient space and water heat pumps, and disconnect natural gas service from all low- and moderate-income households by 2030 if a PIPP is not in place by 2025, and by 2038 at the latest if it is. (A PIPP will insulate low- and moderate-income households from the impact of natural gas rate increases implicit in current policies (see **Chapter 4**). All fuel oil- and propane-heated households should be prioritized for conversion by 2030, since that will have a disproportionately large impact in reducing energy cost burdens and the scale of assistance needed.
 - b. All new detached residential construction starting on January 1, 2025 should be all electric and net-zero in terms of electricity consumption based on annual rooftop solar generation.³⁸⁸
 - c. All other new residential construction should be all-electric starting in 2025.
 - d. No new natural gas connections to buildings should be permitted starting on January 1, 2025; this is important for all customers on the natural gas system because they all pay for the distribution system costs that are in the rate base of regulated natural gas companies.
 - e. All incentives for new natural gas appliances should be ended by the end of 2023.
 - f. Incentives should be provided to landlords for weatherization and electrification of their properties, subject to the benefits of lower energy bills accruing to the tenants (via lower rent in the case of master-metered buildings);
 - g. Landlords should be required by law to give access to their properties for the purpose of energy audits.
8. A “green and healthy homes” approach should be adopted for retrofits; this will enable all low-and moderate-income homes to be eligible for weatherization assistance

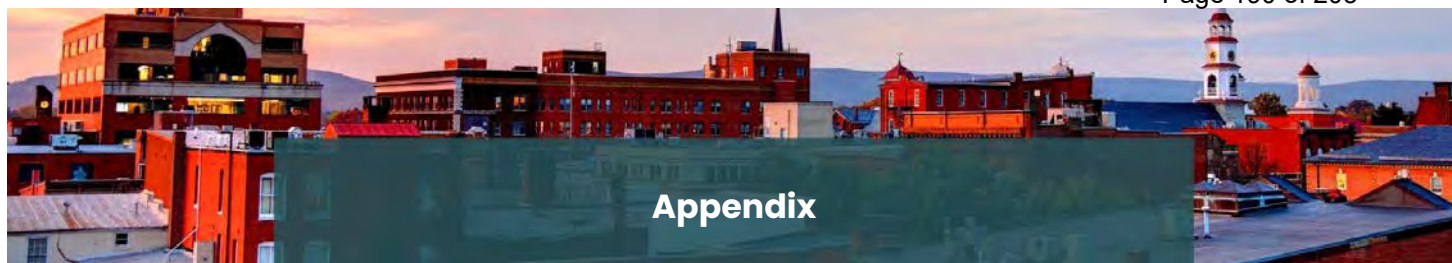
<https://mde.maryland.gov/programs/air/ClimateChange/MCCC/Documents/2021%20Annual%20Report%20FINAL%20%282%29.pdf>

³⁸⁸ For the economics of such construction and an analysis of what a net-zero mandate is preferable to a “solar-ready” policy see Arjun Makhijani, *Gold on the Roof: The Economics of a Net-Zero-Energy Rooftop Solar Mandate for New Residential Housing in Montgomery County, Maryland*, Institute for Energy and Environmental Research, December 2020 at <https://ieer.org/wp/wp-content/uploads/2020/12/Gold-on-the-Roof-Economics-of-New-Detached-Net-zero-Energy-Homes.pdf>

program grants and all such homes to be weatherized to improve both the economic and health outlook of families at the same time.

9. Caution should be exercised when implementing energy efficiency retrofits to ensure that programs do not reduce household ventilation, resulting in degraded indoor air quality. This is in line with the existing DHCD approach to retrofits. Energy efficiency programs should be coupled with electrification and/or ventilation and filtration programs for climate and health benefits to be realized. Educational campaigns should promote activities that increase ventilation during cooking (e.g., using range hood, opening windows) as a precaution whenever cooking occurs.
10. Electrification of household appliances, particularly those located within the living space, e.g., stoves, ovens, space heaters, can eliminate combustion-related emissions that contribute to poor indoor air quality and increased health risks. Policies and programs that support electrification of household appliances can help people who want to transition to electric, but cannot afford to do so.
11. Institutions such as the Maryland Clean Energy Center, a state-chartered non-profit, and the Montgomery County Green Bank, and the non-profit, Climate Access Fund, can be among the vehicles for providing low-cost financing for low- and moderate-income household needs.
12. Net metering for rooftop and community solar subscriptions should be maintained for low- and moderate-income households who have benefited very little from Maryland's solar policies and expenditures so far.
13. Purchase of Receivables should be made available for community solar subscriptions to enable subscribers to receive a single bill and avail themselves of any bill payment assistance for which they may still be eligible.
14. Most low- and moderate-income households will have an incentive to subscribe to community solar after electrification because it would enable them to reduce their energy cost burden to well below six percent. Many households at the lowest income levels will likely still have energy cost burdens over six percent even after weatherization and electrification. Subscriptions to community solar (discounted by at least 20 percent) should be part of an application for assistance under a PIPP program, provided subscriptions are available at that time.
15. Maryland should put in place a comprehensive effort to measure indoor air pollution before and after electrification, especially where it concerns cooking and use of portable fossil fuel heating devices. The benefits of reducing indoor air pollution should be added to the non-energy benefits of electrification and ending the use of natural gas in residential settings.

16. The state should issue guidelines for indoor air pollution that are comparable to or more stringent than outdoor air pollution standards. While guidelines would not be enforceable at first, consistent exceedance should trigger their conversion into requirements for landlords to provide ventilation hoods and properly tuned equipment in rental housing.
17. The Maryland Public Service Commission has ruled that non-energy benefits should be taken into account when evaluating the costs and benefits of ratepayer expenditures on energy efficiency. The same reasoning should be comprehensively applied to estimating the non-energy benefits of a PIPP and of full and rapid integration of low- and moderate-income households into the energy transition that is required to meet the targets of the Climate Solutions Now Act.

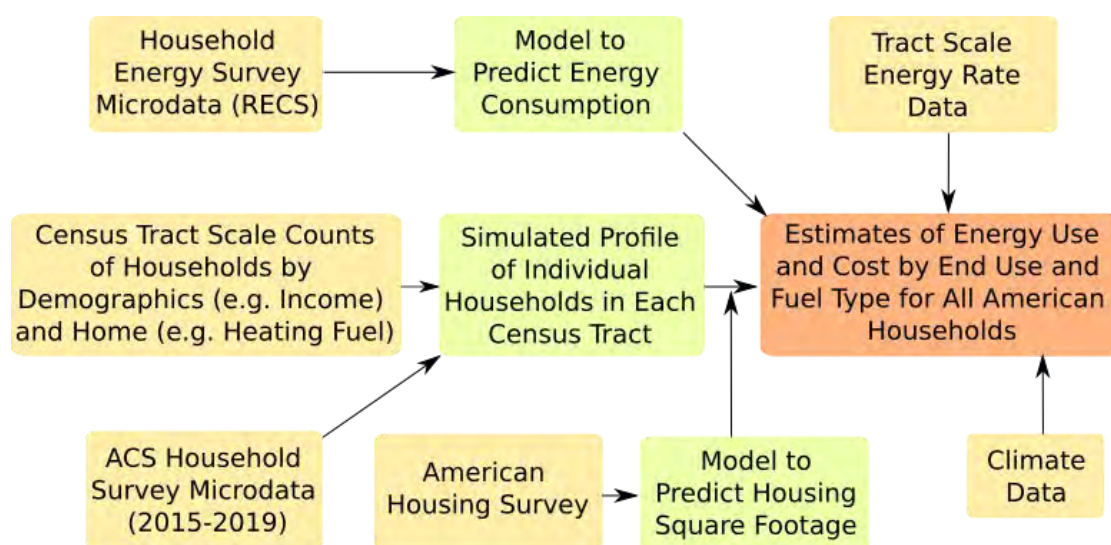


A.1 Energy Affordability Estimates

A.1.1 Methodology

To estimate energy bills, we use models to integrate data from multiple publicly available sources. These methods build upon methods recently used for a similar analysis for the state of Colorado.³⁸⁹ We outline the method here along with comparisons with available datasets for validation purposes. Code for generating these estimates are available upon request.

Figure A-1: Flowchart of modeling for estimation of household energy spending.



Our model roughly follows the flowchart shown in **Figure A-1**. We break the flowchart down into steps as follows:

1. **Predictive model of energy by end use and fuel type.** The Residential Energy Consumption Survey (RECS),³⁹⁰ provides a detailed profile of over 5,000 homes in the year 2015 and their energy use. RECS was designed to capture the wide diversity of

³⁸⁹ Boris Lukanov, Arjun Makhijani, Karan Shetty, Yunus Kinkhabwala, Audrey Smith, and Elena Krieger. Pathways to Energy Affordability in Colorado (2022). *Physicians, Scientists, and Engineers for Healthy Energy*.

³⁹⁰ U.S. Energy Information Administration (2015). Residential Energy Consumption Survey. <https://www.eia.gov/consumption/residential/data/2015/>

homes across the United States and uses bill data obtained directly from utilities to survey the energy usage. This utility-reported data is more reliable than relying on self-reported data such as the American Community Survey (ACS), but is not as extensively sampled. The predictor variables we choose are home type, fuel type, cooling degree days, heating degree days, number of household members, square footage, and the number of rooms. These are chosen because they correlate with energy usage and, for most of them, are available at the census tract scale. The dependent variables we estimate are the total energy as well as the energy used for water heating, space heating, appliances, and space cooling. This builds upon previous methods in the literature, but uses a random forest model as opposed to linear models to avoid issues such as over-fitting or unrealistic estimates outside the domain of what has been observed. This model trained on RECS data can then estimate energy consumption when given a set of predictor variables.

2. ***Building a portfolio of household scale data.*** The U.S. census provides the counts of households in census tracts by demographic attributes and home attributes such as the fuel used for space heating. We use American Community Survey (ACS)³⁹¹ data for the period 2015-2019. Due to privacy concerns, however, the number of cross tabulations are limited. For example, while we may know the total number of households in detached homes, race, and the number of households that rent, we cannot know the number of households that rent, are in detached homes, and identify as White. However, we expect these variables to be correlated. Correlations between these variables can be found in the detailed responses for each survey as found in the ACS microdata that are available in Public Use Microdata Area (PUMA) geographies. We detailed cross tabulations through integration of these data using methods from combinatorial optimization. Broadly speaking, we use optimization methods to select households from the ACS survey microdata in Maryland and neighboring states for each census tract so that the total number of households matches the tallies reported by the ACS. This preserves correlations between variables, such as the fact that low-income households are more likely to be renters. We additionally use American Housing Survey (AHS)³⁹² and RECS data to build models that predict the home square footage, fuel used for water heating, and the fraction of appliance energy use broken down by fuel type since these are not provided by the U.S. census but are available and can be useful for modeling. Using this method, we are able to get a simulated profile for each household in every census tract. We do not expect these tallies to be

³⁹¹ United States Census Bureau. American Community Survey Microdata (2015-2019). <https://data.census.gov/mdat/#/>

³⁹² United States Census Bureau. American Housing Survey. <https://www.census.gov/programs-surveys/ahs.html>

exact at the household scale. For example, multifamily housing in one tract may be high-end luxury housing while another tract may be dominated by low-income multifamily housing. However, aggregate statistics across multiple tracts are reliable and interpretable. Importantly, the disaggregation of tracts into households is vital to reaggregation as demonstrated throughout this report to calculate the affordability for homes according to a given variable such as the fuel type used for heating.

3. **Estimating energy consumption for households.** We take the households simulated in step 2 and enter them into the model built in step 1 in order to estimate the total energy and the energy used for each of the four end uses for each home. We also incorporate estimates of the heating and cooling degree days from nearest weather stations that provide such data.
4. **Calculating spending.** To translate energy use into total annual energy bills, we need the price of each fuel. Due to limited data availability for the delivered fuels, we rely on statewide estimates provided by the EIA for fuel oil and propane costs. More data, however, is available for the electric and natural gas utilities as surveyed by the EIA forms 861 and 176 respectively. We use these to calculate energy rates for each large utility. We then use geospatial methods to assign homes in census tracts to utilities while aligning the total number of customers. This is inexact due to overlapping utility service areas and a lack of alignment of service areas with census tracts, but can be relied upon to capture the regional differences in natural gas and electric rates. We then use these rates to calculate total energy spending and spending broken down by end use.

A.1.2 Validation

No data set of residential energy affordability currently exists at the household scale for all households in Maryland. To perform comparisons of our data with other estimates, then, we shall aggregate it according to data sets and modeled data that do exist and perform comparisons.

A.1.2.1 Average Bill Comparisons

The RECS survey from 2015 reports average energy bills by census division³⁹³ shown in **Table A-1** corrected by an energy-based inflation factor of 17 percent to the year 2021.³⁹⁴ For Maryland, the average of the energy bills we estimate is \$2,233 and \$2,035 for just low- and moderate-income (LMI) households. Maryland is situated in the northmost part of the South

³⁹³ <https://www.eia.gov/consumption/residential/data/2015/c&e/pdf/ce1.1.pdf>

³⁹⁴ <https://www.in2013dollars.com/Energy/price-inflation/2015-to-2021?amount=1>

Atlantic Region whose average annual energy bill is \$2,297, a 3 percent difference than estimated values here. The LEAD tool estimates \$2,386. However, a recent APPRISE report estimated the average Maryland bill for households with incomes less than twice the federal poverty level to be \$2,647, 27 percent greater than the bills estimated for LMI used in this report.

Table A-1: Average Annual Energy Bills from RECS

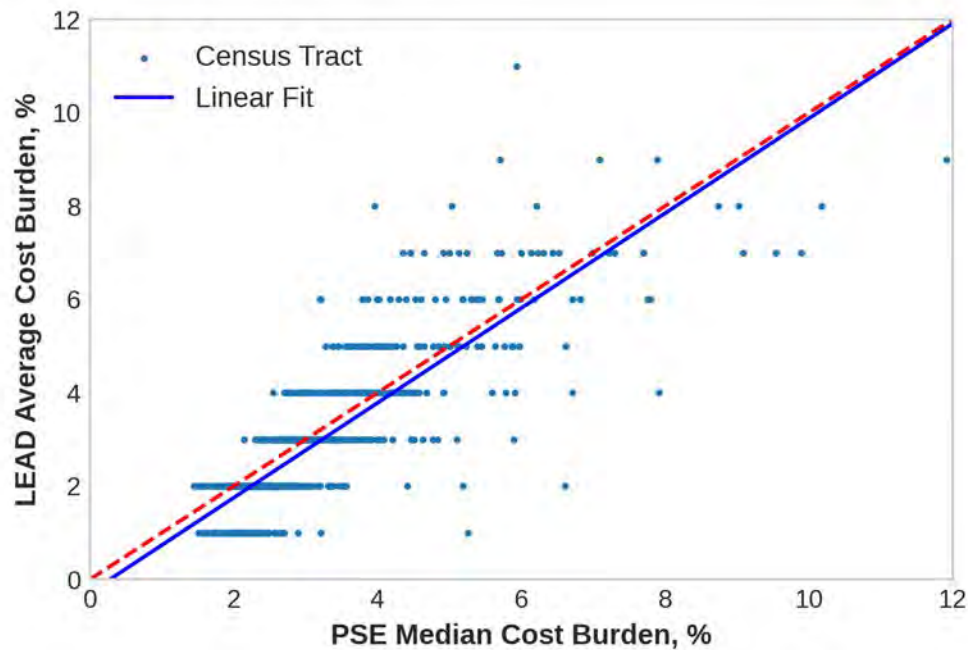
Census Division	Annual Energy Bill Adjusted for 2021
Northeast - New England	\$2,973
Northeast - Middle Atlantic	\$2,537
Midwest - East North Central	\$2,061
Midwest - West North Central	\$2,055
South - South Atlantic	\$2,296
South - East South Central	\$2,231
South - West South Central	\$2,156
West - Mountain North	\$1,855
West - Mountain South	\$1,974
West - Pacific	\$1,709

A.1.2.2 Affordability Gap and Cost Burden Comparisons

The Low-Income Energy Affordability (LEAD) Tool developed by the Department of Energy provides energy affordability data down to the census tract scale and allows for granular comparisons of affordability. In fact, the second step in the methodology described above is similar between our methods and that of the LEAD tool. The biggest difference is that we also use a model for predicting energy consumption while the LEAD tool uses surveyed data of energy bills from the ACS to estimate bills. While the LEAD data is very useful, it does not make public household scale estimates nor their intersections with demographic variables and so we chose to perform our own estimates in order to build custom aggregations and to have available the energy use data in addition to the bill data. In **Figure A-2**, we provide a comparison between the energy cost burdens reported by the LEAD tool and the median cost burdens we estimate. As shown by the blue linear line of best fit, the general trend of our estimates are in agreement with the LEAD tool, however, there is still noise that results from

many factors such as the different sources of energy data and different statistical methods used to aggregate burdens at the tract scale.

Figure A-2: Comparison between PSE and LEAD tool reported census tract energy cost burdens.



Points on the red dashed line have identical values between the two estimates. Solid blue line is the linear line of best fit for the blue scatter points.

Fisher, Sheehan, and Colton first introduced the energy affordability gap metric and have provided estimates of these gaps down to the county scale across the U.S. for years. These estimates have been widely used, providing critical quantification of the gaps of the types we estimate here and steering decision-making into energy affordability. However, our estimates of energy cost burdens tend to be lower than the estimates of Fisher, Sheehan, and Colton. This is most likely due to differences in estimates of energy bills which is the data that must be estimated. For 2021, the year under consideration in this report, we present a comparison between the gaps and energy cost burdens at the county scale in **Table A-2**. One explanation for the much higher energy cost burden for the income groups below 50 percent of federal poverty level is that our estimate is based on a house-to-house energy and income analysis, while Fisher, Sheehan, and Colton calculated the median energy cost burden assuming a single income value set at 40 percent of federal poverty level. In effect, the median income

within the group of households that have less than 50 percent of federal poverty level is considerably less than 40 percent of federal poverty level.

Another potential reason estimates made by Fisher, Sheehan, and Colton are higher than ours is due to an additional stringent affordability limit for heating alone of 2 percent of income. This criterion may add a considerable amount to the affordability gap for the same energy bills. We have not included the additional affordability criterion in our affordability gap estimates.

Table A-2: Comparison of Energy Cost Burdens by Income Groups

Income Group	Fischer, Sheehan, and Colton Home Energy Cost Burden	PSE Median Energy Cost Burden
Below 50%	35%	45%
50-100%	19%	14%
100-125%	12%	9.4%
125-150%	10%	7.8%
150-185%	8%	6.4%
185-200%	7%	5.6%

A.1.2.2 Total Maryland Consumption

The EIA reports the total residential energy consumption by fuel type across Maryland³⁹⁵ shown in **Table A-3**.

Table A-3: Comparison of total energy consumption reported by the EIA and estimated by PSE.

Energy Source	EIA SEDS (2020) Trillion BTU	PSE Estimate, Trillion BTU
Fossil Gas	80.4	79.8
Electricity	93.2	88.7
Fuel Oil	10.7	9.0
Propane	7.3	4.9

³⁹⁵ EIA State Profiles and Energy Estimates

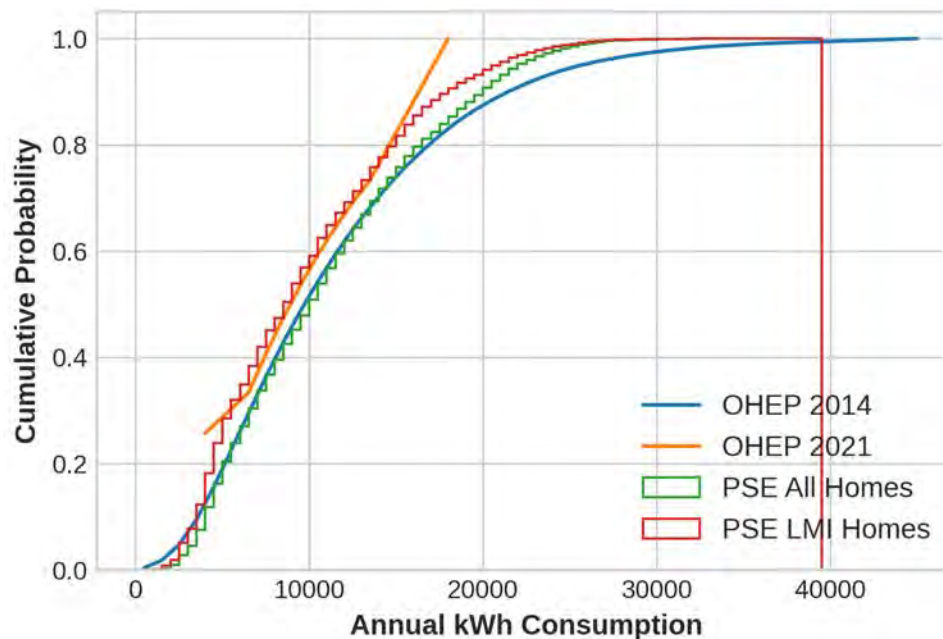
https://www.eia.gov/state/seds/data.php?incfile=/state/seds/sep_sum/html/sum_btu_res.html&sid=US

Estimates from our model are lower for each of the fuels but within a few percent for the most commonly used fuels. Propane has the greatest proportional discrepancy of 30 percent. For scale, however, we note that the energy difference between EIA's reported value and PSE's estimated value is the equivalent of roughly 5,000 small tanks of propane of the type typically used for outdoor grills, an end-use common across all homes that may not be fully accounted for in our data. Discrepancies for other fuels could have multiple causes. It could be caused by homes that have outlier usage such as very leaky or very large homes as discussed in **Section 2.7.2**. This discrepancy could also be a systematic difference for Maryland in which homes systematically use slightly larger amounts of energy than our model predicts. Likely, it is due to a combination of such factors and so we choose to use the data as is and advise that there exist homes with especially high bills that are not fully accounted for in this analysis.

A.1.2.3 OHEP Energy Usage Statistics

The Office of Home Energy Programs (OHEP) has collected surveys of energy bills for low-income households. Within these data, they provide the total number of homes within electricity usage brackets. We compare the distributions of electricity usage from our estimates with values reported by the OHEP for the years 2014 and 2021 in **Figure A-3**. The year 2021 had fewer brackets and so the curve is limited to a smaller range. In 2021, energy use was less due to differences in weather and possibly improvements in efficiency.

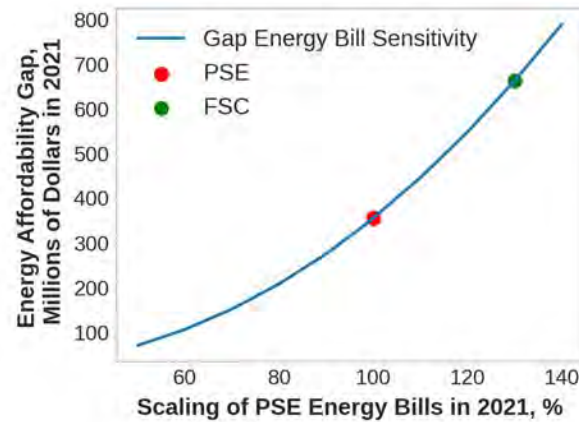
Figure A-3: Cumulative distributions of annual electric energy for surveyed homes from two OHEP reports (2014 and 2021) and from estimates used in this report for all households and for just LMI households.



A.1.2.4 Sensitivity Analysis

A part of the difference in the aggregate estimate of the affordability gap of about \$400 million in this report and the Fisher, Sheehan, and Colton gap of \$709 million is due to the latter's use of an additional 2 percent affordability threshold for heating. We have not included this additional threshold in our analysis. However, a part is due to the higher energy bill estimates in Fisher, Sheehan, and Colton relative to the ones in this report. **Figure A-4** shows the non-linear sensitivity of the affordability gap to energy bill estimates assuming it is due to energy bills alone. As bills increase, the affordability gap increases more rapidly due to additional households being pushed beyond the 6 percent affordability threshold. The actual discrepancy between our affordability gaps estimate and that of Fisher, Sheehan, and Colton is likely less than that indicated in **Figure A-4**.

Figure A-4: Sensitivity analysis of the total affordability gap on the scaling of energy bills estimated in this report.



A.1.2.5. Discussion of Potential Sources of Discrepancy in Energy Usage and Bills

Energy usage differences between reported values from the EIA, OHEP, and RECS and those estimated here are in general agreement and not sufficient to describe disparities between our estimated annual bills and affordability metrics as those provided by APPRISE or Fisher, Sheehan, and Colton. In the absence of more detailed information about the estimation methods and underlying data sources, we can only speculate about the source of these different estimates.

One possible reason for the different energy bill estimates is a difference in the choice of the underlying data. In our analysis, energy related consumption was estimated from RECS and then merged with rates estimated from reported sales and revenues, other estimates often rely on the ACS self-reported energy bill data. These data ask respondents to report their last month's energy bill. This data must then be integrated and modeled in order to determine the full year's energy bill, but it has the advantage of a greater sample size and spatial granularity compared to the RECS data. It has been observed, however, that responses tend towards higher estimates of energy bills that must be corrected for.

Different accounting methods of energy consumption variations between low-income households and the remainder of the population may also be a factor. For example, randomly assigning energy bills to households regardless of income results in an increase of the total energy affordability gap from roughly \$350 million to \$510 million. This is because, after shuffling energy bills, low-income households will be spending as much as higher-income households on average.

A.1.3 Energy Estimates Summary

Given above comparisons and the comparisons between our estimates and EIA data in Table A-3 above, our estimate of an affordability gap of \$350 million is likely to be underestimated by about \$50 million. This captures the differences in energy usage reported by the OHEP bills and EIA combined with rough estimates of climate sensitivities. We have accordingly adjusted our total estimate of the gap to \$400 million.

We recommend more reporting from utilities to resolve discrepancies discussed here and to allow a finer scale of analysis while still protecting customer privacy. It is challenging to make more accurate estimates of the affordability gap with publicly available data. Lack of utility data (appropriately anonymized) presents unnecessary obstacles to the analysis and design of programs and public policies. One simple solution would be clear and accessible reporting of utility rate structures for gas and electricity. This would additionally clarify what portion of bills are fixed connection fees and what portions are consumption based and allow for better modeling of the impacts of rate structures on affordability. Additionally, consumption and revenue data at a finer scale than that reported by the EIA-861 and EIA-176 forms would be useful. For example, these same data could be reported not just by utility but also by county. This would be especially useful for understanding the impact of retail choice services that have no utility service area and thus provide no way of locating where their customers live and how much beyond the local base rate they are paying.

Energy Use, Indoor Air Quality, and Health Methodology

We conducted a brief review of relevant literature that demonstrated the impacts of residential energy efficiency, household fuel combustion, ventilation, and electrification retrofit measures on indoor air quality and health in residences across the United States. We conducted a literature search of peer-reviewed journal articles published from January 1, 2010 to June 13, 2022. We also considered selected additional studies published after this timeframe as well as government reports and white papers from federal agencies and Maryland-based institutions in our review. We prioritized peer-reviewed literature focused in Maryland, Baltimore City, and the Northeast, United States, but considered all U.S.-based studies. Although other factors can contribute to indoor air quality and are relevant to consider in a health context (e.g., off-gassing of household products, mold), in this review, we restricted our literature search to studies focused on energy use (fuel types and appliances), energy retrofits (efficiency measures such as weatherization), and the availability, efficiency, and utilization of mechanical ventilation (hood fans) and filtration systems (HVAC). As such,

we excluded studies not focused on the United States and studies that focus on indoor air quality but that did not evaluate the impacts of appliances, energy use, and/or energy retrofits on indoor air quality or health.

While this report is not a comprehensive review of available peer-reviewed literature, we relied upon the following set of search terms in Web of Science to help identify articles relevant to this assessment. The search, conducted on June 13, 2022 was restricted to articles published on January 1, 2010 or later.

TS=(“residential” OR “household*” OR “home*” OR “apartment*” OR “single-family*” OR “multifamily*” OR “multi-family*” or “housing*”) AND TS=(“healthy home*” OR “retrofit*” OR “energy use” OR “indoor energy use” OR “energy usage” OR “energy upgrade*” OR “electrification” OR “energy transition” OR “electrify” OR “energy efficiency” OR “weatherization” OR “weatherize” OR “efficiency upgrade*” OR “appliance upgrade*” OR “fireplace*” OR “wood stove*” OR “pellet stove*” OR “ventilation” OR “hood fan*” OR “vent hood*”) AND TS=(“Formaldehyde” or “indoor ambient air” OR “indoor air quality” OR “indoor air*” OR “indoor air pollutant*” OR “indoor air contaminant*” OR “indoor air pollution” OR “IAQ” OR “carbon monoxide” OR “benzene” OR “formaldehyde” OR “ultrafine*” OR “polycyclic aromatic hydrocarbon*” OR “PAH*” OR “particulate matter” OR “PM” OR “PM1” OR “PM2.5” OR “PM10” OR “NOX” OR “NO2” OR “nitrogen oxide*” OR “nitrogen dioxide” OR “hazardous air pollutant*” OR “hazardous*” OR “toxic air contaminant*” OR “TAC” OR “air toxic*” OR “health damaging” OR “air pollutant*” OR “volatile organic compound*” OR “VOC” OR “respiratory” OR “pulmonary” OR “cardiopulmonary” OR “cardiac” OR “neurologic*” OR “disease” OR “health” OR “epidemiological” OR “symptom*” OR “health risk*” OR “physiological” OR “hospitalization” OR “asthma” OR “injury” OR “mortality” OR “cancer” OR “morbidity” OR “adverse pregnancy outcomes” OR “birth” OR “congenital” OR “birth defects” OR “birth weight” OR “low birth weight” OR “preterm birth” OR “premature birth” OR “preterm delivery” OR “small for gestational age” OR “LBW” OR “PTB” OR “PTD” OR “SGA” OR “fetal death” OR “cardiovascular” OR “exposure”) AND TS=(“Maryland” OR “Baltimore City” OR “Baltimore” OR “United States” OR “US” OR “U.S.” OR USA OR Alabama OR Alaska OR Arizona OR Arkansas OR California OR Colorado OR Connecticut OR Delaware OR Florida OR Georgia OR Idaho OR Hawaii OR Illinois OR Indiana OR Iowa OR Kansas OR Kentucky OR Louisiana OR Maine OR Maryland OR Massachusetts OR Michigan OR Minnesota OR Mississippi OR

Missouri OR Montana OR Nebraska OR Nevada OR “New Hampshire” OR “New Jersey” OR “New Mexico” OR “New York” OR “North Carolina” OR “North Dakota” OR Ohio OR Oklahoma OR Oregon OR Pennsylvania OR “Rhode Island” OR “South Carolina” OR “South Dakota” OR Tennessee OR Texas OR Utah OR Vermont OR Virginia OR Washington OR “West Virginia” OR Wisconsin OR Wyoming OR “Washington DC” OR “Washington D.C.” OR “D.C.” OR “District of Columbia” OR “Appalachia” OR “northeast” OR “southeast”) NOT TS=(“China” OR “Switzerland”)

Acronyms and Abbreviations

BIESAK	Baltimore Indoor Environment Study of Asthma in Kids
CalEPA OEHA	California Environmental Protection Agency Office of Environmental Health Hazard Assessment
CAAQS	California Ambient Air Quality Standards
CHD	coronary heart disease
CO	carbon monoxide
CO ₂	carbon dioxide
CO ₂ -e	carbon dioxide equivalent
COHgb	carboxyhemoglobin
DHCD	Department of Housing and Community Development
ECB	energy cost burden
EJ	environmental justice
FPL	federal poverty level
HAP	hazardous air pollutant
HI	hazard index
HVAC	heating, ventilation and air conditioning
IAQ	indoor air quality

IRA	Inflation Reduction Act
LMI	low- and moderate-income
MD	Maryland
mg/m ³	milligrams per cubic meter
NAAQS	National Ambient Air Quality Standards
NO	nitrogen monoxide, nitric oxide
NO _x	nitrogen oxides
NO ₂	nitrogen dioxide
NYS HNP	New York State Healthy Neighborhoods Program
OHEP	Office of Home Energy Programs
PAH	polycyclic aromatic hydrocarbon
PM	particulate matter
PM _{1.0}	ultrafine particulate matter less than or equal to 1.0 micron in diameter
PM _{2.5} diameter	fine inhalable particulate matter less than or equal to 2.5 microns in diameter
PM _{2.5-10}	particulate matter equal to 2.5-10 microns in diameter
ppb	parts per billion
ppm	parts per million
REL	reference exposure level
SO ₂	sulfur dioxide
µg/m ³	micrograms per cubic meter
µg m ⁻³	micrograms per cubic meter
U.S.	United States
U.S. EPA	United States Environmental Protection Agency

VOC	volatile organic compound
WHO	World Health Organization

Demand Response

About Demand Response

Program Options

Find an Option That Works for You

Review and compare your six Demand Response options below to find the one that works best for you. Each option includes a link to more details, benefits, requirements and information on how to enroll or switch to your preferred choice.



SmartCurrents™

Suitable for your household if you're in the market for a smart thermostat. You'll receive a **free Wi-Fi-enabled ecobee Smart Thermostat Premium** - a \$249 value.

Events: SmartCurrents Peak Events may be called on weekdays for up to four hours between noon and 8 p.m. during periods of high demand, like a heat wave. Events won't exceed 64 hours total each year.

We'll professionally install your **free smart thermostat at no charge.**

During SmartCurrents Peak Events we'll adjust your thermostat automatically by up to four degrees to help you save. You can choose to opt out of an event at any time or adjust your settings based on the impact you want to have.

Get an **annual incentive** – a \$25 bill credit – by remaining on the program for 12 months and for each subsequent 12-month period.

SmartCurrents benefits and requirements

"I received mine a few weeks ago. I didn't know how to set it up, so I called DTE – they sent someone, and it only took 5 minutes for him to install it. Very easy process. I love being able to adjust my temperature from my phone so when I'm out I can keep the heat low."

– Jenny M., Participant since 2020



Smart Savers

Perfect for residential electric customers who already have a smart, Wi-Fi-enabled thermostat installed.

Events: During Smart Savers events, all participating thermostats will be automatically adjusted up to four degrees from the thermostat's original setpoint. Adjustments typically last no more than four hours between 12 p.m. and 8 p.m. on weekdays and non-holidays from June 1 through September 30.

Provides a **simple way to save** that requires no effort on your part during scheduled Smart Savers events.

You are rewarded for participating in Smart Savers events during periods of high electric demand.

You'll receive a **\$50 bill credit** each year you participate in events.

Smart Savers benefits and requirements

"Frequency of communication is good, not too much, and its direct and helpful."

– Simon C., Participant since 2022



CoolCurrents®

Ideal for residential electric customers with central air conditioning or a whole-home air source heat pump who can install an additional **smart meter** and a 24-volt power source connection.

Events: During events, we'll briefly cycle your air conditioning or air source heat pump in 15-minute intervals by sending a signal to the device. The cycling of your equipment will be limited to no more than eight hours in a 24-hour period and no more than 30 minutes per hour.

Includes a **discounted Interruptible Space Conditioning rate** designed to help you save when compared to the Time of Day 3 p.m. – 7 p.m. rate:

Save up to 32% on the cooling portion of your energy bill throughout June and September during peak hours.

Customers with a whole-home air source heat pump **save up to 20%** on the electric heating portion of their energy bill during peak hours.

CoolCurrents benefits and requirements



Water Heating Service

Great for your household budget if you can allow temporary interruptions of electricity to your water heater and have a separately metered circuit for water heating.

Events: There may be temporary interruptions of electricity to your water heater for up to four hours per day.

Provides a **lower rate** for electric water heater usage.

Water heating benefits and requirements



DTE Smart Charge

Ideal for electric vehicle (EV) drivers that would like their EV's home charging to occur during off-peak time periods, based the time of use electric rate schedule they're on.

Overview: DTE Smart Charge helps EV drivers manage their charging during times of the day that help the energy grid operate more efficiently. DTE Smart Charge will schedule daily charging to meet your charging needs and will occasionally shift charging to help optimize the energy grid.

You'll always have control of your participation and can opt out of an event at any time.

You receive up to \$100 in gift cards for enrollment and participation.

 [Smart Charge benefits and requirements](#)



Dynamic Peak Pricing

Suitable for your household if you can be flexible with some of your electricity use. Doing this lets you take advantage of lower rate periods during off-peak weekday hours and weekends.

Events: Critical Peak Events may be called on weekdays from 3 p.m. to 7 p.m. During these intermittent events (up to 14 per year), you'll be charged \$1.03 per kWh. You'll be notified at least six hours before any event, so you're prepared.

Significantly discounts the cost of electricity from 11 p.m. to 7 a.m. on weekdays and all weekend.

You save money by shifting some of your electricity usage — like doing laundry or running the dishwasher — to weekday mornings and evenings or all day on weekends.

Dynamic Peak Pricing benefits and requirements

"I now do laundry mainly on the weekend or after 7 p.m. I also only run the dishwasher at night. These alone are saving us money."

– Stephen O., Participant since 2016

Explore Other Electric Pricing Options

DTE offers two additional tiered pricing options that are separate from Demand Response. Learn more about:

Time-of-Day option from 3 p.m. to 7 p.m.

Time-of-Day option from 11 a.m. to 7 p.m.

Please visit [Electric Pricing Options](#) to review all your electric pricing alternatives, add-ons, and incentives.

MIDWEST

Department of Energy looks to Illinois to lead on low-income community solar

Existing social service and energy assistance programs are key to increasing participation, federal and state leaders say.



by Kari Lydersen
August 18, 2022



Credit: Kelly L / Creative Commons

Illinois is one of five states where the U.S. Department of Energy is **piloting a program** to expand community solar for low-income households by leveraging an existing federal low-income heating and cooling assistance program.

Solar programs aimed at low-income customers in Illinois and elsewhere have often struggled because of bureaucratic and pragmatic barriers including verifying income qualifications and recruiting participants.

The idea behind the new effort is that customers who have already been approved for bill assistance through the federal Low Income Home Energy Assistance Program, or LIHEAP, can be smoothly integrated into community solar programs, avoiding additional income verification requirements and building on the long-standing recognition and trust that program enjoys. The U.S. Department of Health and Human Services is also part of the initiative.

The DOE is enlisting community organizations that have long helped connect residents with LIHEAP, as well as solar developers and other stakeholders, to develop a “digital platform” for low-income community solar. The department is asking for feedback by Aug. 31 on how to design the platform, which would likely be a website or dashboard.

“The idea of the tool itself is to be a bridge between those agencies that interface with LIHEAP recipients and community solar subscription managers,” said Nicole Steele, DOE senior advisor for equity and workforce access and head of the National Community Solar Partnership. “We’d be working directly with those organizations to make sure we’re creating the right materials to communicate the benefits of community solar and what it means to sign up for a subscription. How do you interact with your utility bill and subscription going forward, figuring out how to best streamline the process. We want to make sure we hear from everyone who is part of this puzzle.”

DOE chose Illinois because of its low-income community solar program that was started by a 2016 energy law and expanded by a law passed last year. Pilot programs are also being launched in Colorado, New Jersey, New Mexico, New York, and Washington, D.C. The program was announced in late July, in tandem with news that the Bipartisan Infrastructure Law would fund \$10 million for solar job creation in underserved communities. The DOE has a goal of connecting 5 million homes nationwide to community solar by 2025, which would increase the country’s current 3 GW of community solar to 20 GW. The department also wants to increase average bill savings from community solar from 10% currently to 20% by 2025.

In Illinois specifically, DOE estimates that households could save \$300 million a year through community solar.

Groundwork in Illinois

Illinois’ low-income community solar program — part of the larger Illinois Solar for All initiative — has already been popular and successful, said Jennifer Schmidt, Solar For All program manager for the Illinois Power Agency, which oversees the state’s renewable targets.

While administrators have struggled to drum up interest in Solar for All's programs for low-income household solar, the low-income community solar program has seen more applications than subscriptions available. The developers building low-income community solar get the right to sell renewable energy credits at high prices, and participants are guaranteed 50% bill savings.

This year, the Illinois Power Agency approved six low-income community solar projects with a total capacity of 7.4 MW and allocated \$21.3 million in incentives. Since the program started in 2017, 17 projects totaling almost 20 MW have received over \$57 million in incentives.

The Illinois Association of Community Action Agencies and its member groups have helped enlist subscribers, holding 29 presentations for more than 400 people across the state and sending mailings to LIHEAP and Head Start participants.

"It is through these successful partnerships with locally rooted organizations that the [Solar for All] Program has been able to provide greater access to the clean energy economy for low-income communities," Schmidt said.

The Climate and Equitable Jobs Act passed last year expanded Solar for All, making more community solar incentives available.

"We believe the pilot platform will provide an opportunity for income-eligible households to find and connect to [Solar for All] community solar projects that are looking for subscribers more easily," Schmidt said. "Additionally, we hope this platform will reduce the community solar developers' soft costs of finding eligible participants and provide an equitable and transparent way for [Solar for All]-approved vendors to reach income-eligible households."

The Climate and Equitable Jobs Act removed the burden of income verification from solar developers, tasking the nonprofit that administers Solar for All with that process. The DOE platform and approach would further streamline the process.

"If you're already a LIHEAP participant, there's very little paperwork," said Steele, adding that people registering for LIHEAP for the first time would also be informed about community solar. She noted that the community organizations that help people sign up for LIHEAP are usually "a trusted organization in the local community. We see that as a better model than asking the developers to do verification."



National models

At a webinar about the pilot, officials described the low-income solar programs already underway in New York, New Jersey and New Mexico. In New Jersey, community solar is helping the state toward its goal of carbon-free electricity generation by 2050.

A pilot program has supported community solar projects with at least 51% of subscribers of low to moderate income. So far 126 projects have been built on rooftops, plus 24 projects on sites including landfills, parking lots and a gravel pit, said Veronique Oomen, renewable energy project manager at the New Jersey Board of Public Utilities.

Through a new community solar program based on a law passed last year, New Mexico is hoping to bring savings to low-income households in Indigenous pueblos, rural areas and municipalities, said DOE solar innovator Mary Jane Parks. The state will reach out to participants in LIHEAP, food stamps, subsidized housing, first-time homebuyer and other existing programs. The program caps installations at 5 MW, and mandates that 30% of subscribers be low-income.

“We’d like 12,000 of 239,000 low-income households in investor-owned utility territories to be approached and participate as well as tribal LIHEAP households,” Parks said. “We’d like the program to reflect the diversity of our state.”

However, utility Southwestern Public Service Company has challenged New Mexico’s program in a case that has reached the state Supreme Court.

New York has a goal of 1,600 new megawatts of community solar by 2030 for low- to moderate-income and environmental justice subscribers, including residents of multifamily housing.

DOE leaders on the webinar also advised state leaders to work to ensure that residents of public housing can access bill savings from community solar. Under the typical model where public housing residents pay a third of their income toward rent that includes utility bills, savings from solar would accrue to the housing agency rather than the individual. But the U.S. Department of Housing and Urban Development has issued guidance for states including Illinois and California to help public housing residents benefit from community solar.

Steele said the federal agencies will hold roundtables in the pilot states and otherwise collect feedback and design the program over the next approximately nine months, and the platforms will likely be launched next summer.



[Ready to go electric? Get started today.](#)



[Home](#) / [Policy Hub](#) / [High-Efficiency Electric Home Rebate Act \(HEEHRA\)](#)

High-Efficiency Electric Home Rebate Act (HEEHRA)

Formerly known as the Zero-Emission Homes Act (ZEHA)

The High-Efficiency Electric Home Rebate Act (HEEHRA) provides point-of-sale consumer rebates to enable low- and moderate-income households across America to electrify their homes. HEEHRA will help American families save money on their monthly energy bills, create healthier indoor air environments, and reduce their carbon emissions.

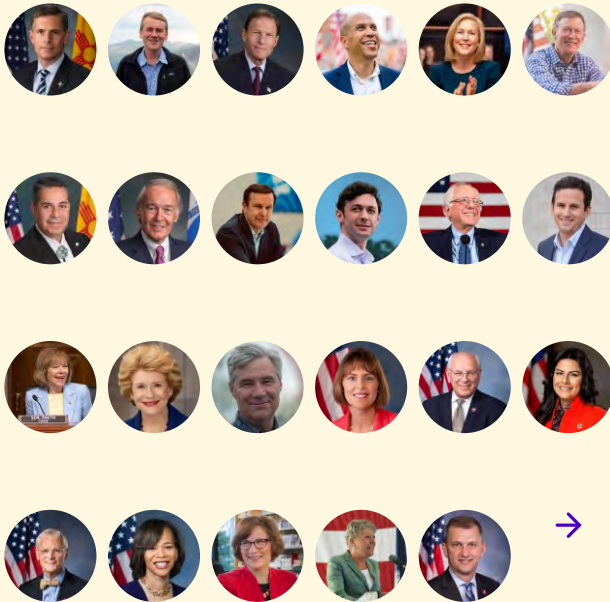
HEEHRA is a voluntary program that covers 100 percent of electrification project costs (up to \$14,000) for low-income households and 50 percent of costs (up to \$14,000) for moderate-income households. Qualified electrification projects include heat pump HVAC systems, heat pump water heaters, electric stoves and cooktops, heat pump clothes dryers, and enabling measures such as upgrading circuit panels, insulation, air sealing, ventilation, and wiring. Project costs will cover both purchase and installation costs. And, notably, these point-of-sale rebates will act as off-the-top discounts when a household makes the purchase.

This historic legislation was included in the Inflation Reduction Act (IRA) of 2022. The original Senate bill — the Zero-Emission Homes Act (ZEHA) of 2021 — was introduced by Senator Heinrich (D-NM), and its House companion was introduced by Representatives Tonko (D-NY) and Castor (D-FL).

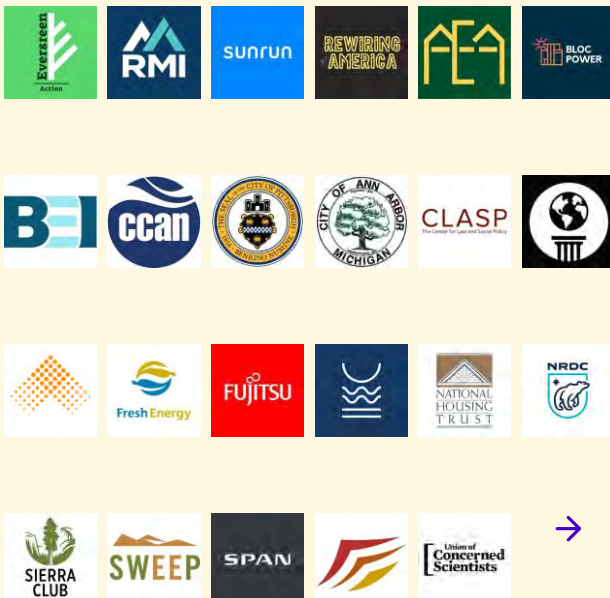
For more information, see our [overview](#) of the IRA's climate provisions, our [breakdown](#) of the IRA's investments in disadvantaged communities, and our [report](#) on the benefits of electrification.

Supporters

U.S. Congress 34



Organizations 250



Highlights

The High-Efficiency Electric Home Rebate Act (HEEHRA) is a 10-year rebate program to support low- and moderate-income (LMI) households who choose to electrify. Specifically, HEEHRA:

- Designates \$4.275 billion in rebate funding to be distributed by State Energy Offices and \$225 million to be distributed by Tribal Governments;
- Establishes point-of-sale consumer rebates for “qualified electrification projects” (see chart), up to \$14,000 per household;
- Covers 100 percent of electrification project costs for low-income households and 50 percent of costs for moderate-income households;
- Extends rebates to multifamily buildings in which 50 percent of residents are LMI; and
- Incentivizes contractors to perform electrification projects in LMI communities.

HEEHRA Rebate Levels For Qualified Electrification Projects	
Income Eligibility and % Costs Covered	
Low-income: <80% Area Median Income (AMI)	
% costs covered (including installation)	100%
Moderate-income: 80-150% AMI	
% costs covered (including installation)	50%
Overall Incentives	
Max consumer rebate	\$14,000
Max contractor rebate	\$500
Rebates for Qualified Electrification Projects	
Heat pump HVAC	\$8,000
Heat pump water heater	\$1,750
Electric stove/cooktop	\$840
Heat pump clothes dryer	\$840
Breaker box	\$4,000
Electric wiring	\$2,500
Weatherization insulation, air sealing, ventilation	\$1,600

Benefits

LOWER BILLS

Almost all households get cheaper energy bills

At least 85% of households in the United States — 103 million — could save \$37.3 billion a year on energy bills



if they were using modern, electrified furnaces and water heaters instead of their current machines.

LARGE SAVINGS

Most households would save an average of \$496 per year

The savings are biggest for the 64.9 million households in the United States across every county who are currently using electric resistance, fuel oil, or propane and would save \$496 per year on average.

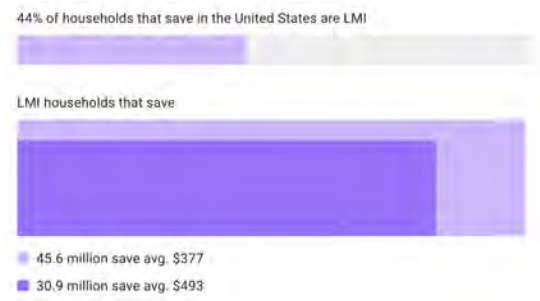
	# of Furnaces	Avg. savings if electrified	# of Water Heaters	Avg. savings if electrified
Electric Resistance	33.83M	\$300 / yr	54.16M	\$282 / yr
Fuel Oil	5.69M	\$407 / yr	3.40M	\$174 / yr
Propane	5.75M	\$447 / yr	4.31M	\$303 / yr

67% of households using natural gas would also save on annual energy bills. The number of households that would save and the average savings will continue to increase given the trajectory of heat pump technology improvements.

EVERYONE BENEFITS

Meaningful savings for low- and moderate-income (LMI) households

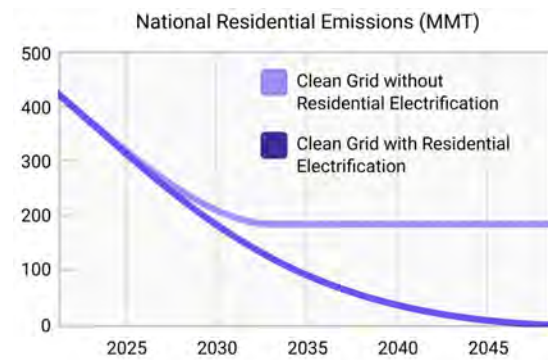
Of the households that save, 44% are low- and moderate income. Each year, they would save an average of \$377. Many would save up to \$493 per year on average.



REDUCE EMISSIONS

It's essential to reaching zero emissions

Furnaces, water heaters, dryers, and stoves account for at least 95% of residential building emissions but are replaced just once every 10-25 years. Unless we choose modern, electrified replacements for these machines, we will continue to need dirty infrastructure to power our homes, never getting to zero emissions.



CREATE JOBS

Hundreds of thousands of new jobs will be created

Electrification would create 462,430 installation jobs in the United States. In addition, it would further generate 80,000 manufacturing jobs and 800,000 indirect and induced jobs.

	Installation	Electricians, plumbers, contractors...
	Manufacturing	Factory, assembly line, and supply chain workers...
	Indirect	Truck drivers, welders, mine engineers, accountants...
	Induced	Service, retail, food & beverage workers, teachers...

IMPROVE HEALTH

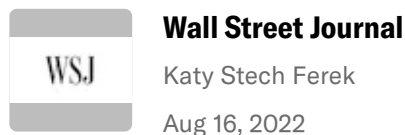
Cleaner indoor and outdoor air

Electrifying these appliances would address the 42% increased risk of children experiencing asthma symptoms associated with gas stove use. Such indoor pollution disproportionately affects low-income households with smaller homes. Furthermore, outdoor air pollution from residential buildings currently accounts for 15,500 premature deaths in the United States per year.

Indoor Pollutants Emitted By Gas Stoves	
NO ₂	Nitrogen Dioxide
PM _{2.5}	Particulate Matter (2.5 microns)
CO	Carbon Monoxide
HCHO	Formaldehyde

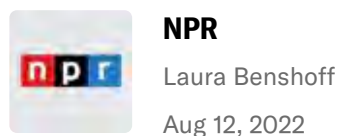
[See the Full Report →](#)

Media Coverage



Makers of Heating, Cooling Systems Expect Climate Bill to Boost Sales

"Anticipating an increase in sales, Mark Kuntz, chief executive of Mitsubishi Electric Trane HVAC US Inc., which makes high-efficiency heat pumps, said the company plans to announce the location of a new 2,000-worker factory by the end of the year on expectations of higher sales. "We think it's going to change the mind-set of the U.S. consumer," he said of the bill, called the Inflation Reduction Act."



3 ways the Inflation Reduction Act would pay you to help fight climate change

"Money in the Inflation Reduction Act would make it cheaper for Americans to curb their own climate-warming emissions. . . . Down the road, the bill would also set aside more than \$8

billion for two rebate programs, aimed at lower- and middle-income households. One would incentivize replacing old appliances with new energy efficient ones, as well as the home upgrades necessary to support them; and another to cut down on energy wasted at home."



Canary Media

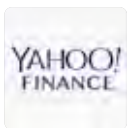
Jeff St. John

Aug 3, 2022

[Climate bill could spur 'market transformation' in home electrification](#)

"Based on today's average prices for heat pumps, these rebates could be expected to cover the full cost of installation for low-income households, according to Lowell Ungar, head of the federal policy program at the American Council for an Energy-Efficient Economy (ACEEE). Moderate-income households could add tax credits to rebates to cover about two-thirds of their total costs, he estimated in an email.

"Utility-bill savings from such upgrades would vary depending on a number of factors. But electric appliances "have already leapfrogged their fossil-fuel competitors on efficiency and performance," U.S. Senator Martin Heinrich, the New Mexico Democrat who sponsored the HEEHRA legislation in the Senate, noted."



Yahoo! Finance

Akiko Fujita

Aug 1, 2022

[Inflation Reduction Act would lead to \\$1,800 in savings for average household, analysis finds](#)

"A program dubbed the High Efficiency Electric Home Rebate Act (HEERA) sets aside \$4.5 billion in direct rebates for low- and moderate-income households that install new, efficient electric appliances. Under the proposed rebate framework, a low-income household would receive a rebate of up to \$8,000 for a new heat pump, \$840 for an electric stove or electric dryer, and \$2,500 for updated electrical wiring, among other rebates. Matusiak said those incentives will enable 1 million households to go electric."



Politico

Matthew Choi

Jun 30, 2021

House Democrats' United Front

"Sen. Martin Heinrich (D-N.M.) unveiled an outline for a new bill Wednesday that would help consumers buy electric appliances and equipment to cut down on household emissions. The Zero-Emission Homes Act of 2021 would offer rebates to buy and install electric appliances at prices competitive with fossil fuel-based alternatives."

[View more](#) (1)

Press Releases



Senator Martin Heinrich

Aug 6, 2022

Heinrich Passes Game-Changing Electrification Provisions In Historic Inflation Reduction Act

"The clean energy and electrification investments that we secured in the Inflation Reduction Act represent by far the most significant steps that Congress has ever taken to spur the widespread deployment of highly-efficient, fully electric and climate pollution free technologies.

"I'm pleased to lead the charge to establish a new rebate program that mirrors my Zero-Emission Homes Act to help families with the upfront costs of installing clean and efficient electric home appliances.

"Because these electric technologies are more efficient and less expensive to operate, they will also help families across the country realize significant savings on their energy bills. This is particularly important at a time when so many Americans have been experiencing the pinch from inflation at the gas pump and in their gas and utility bills. We have moved mountains in the last year, and we are on the verge of getting something very deeply meaningful to the President's desk."



House Select Committee on the Climate Crisis

July 30, 2021

Castor, Tonko Introduce Legislation to Electrify Households, Create Jobs & Lower Energy Bills

"Electrification of household appliances would help millions of families save money on their energy bills every month, while creating over a million new jobs in manufacturing, installing, and servicing these new electric appliances."



Sen. Martin Heinrich

July 15, 2021

Heinrich Leads 11 Senate Democrats in Introducing Zero-Emission Homes Act to Establish New Rebate Program For Home Electric Appliances, Equipment

"Electrifying our homes and businesses is one of the surest climate actions that we can take right now. We can use already existing, proven technologies to dramatically reduce carbon pollution, create millions of good-paying jobs, and secure a more equitable future for our communities."



Rewiring America

June 30, 2021

New Report Shows Electrifying Homes Key U.S. Climate Goals, and Most Americans Will Benefit

"The Zero-Emission Homes Act of 2021 would provide rebates for the purchase and installation of electric appliances and equipment in single-family homes and multifamily dwellings, with additional support for low- and moderate- income households, who spend a larger share of their income on energy than other households."

U.S. Senate



Sen. Martin Heinrich

D-New Mexico

SPONSOR



Sen. Michael Bennet

D-Colorado

CO-SPONSOR



Sen. Richard Blumenthal

D-Connecticut

CO-SPONSOR



Sen. Cory Booker

D-New Jersey

CO-SPONSOR



Sen. Kirsten Gillibrand

D-New York

CO-SPONSOR



Sen. John Hickenlooper

D-Colorado

CO-SPONSOR



Sen. Ben Ray Luján

D-New Mexico

CO-SPONSOR



Sen. Ed Markey

D-Massachusetts

CO-SPONSOR



Sen. Chris Murphy

D-Connecticut

CO-SPONSOR

[View more](#) (6)

U.S. House



Rep. Kathy Castor

D-FL-14

SPONSOR



Rep. Paul Tonko

D-NY-20

SPONSOR



Rep. Nanette Barragan

D-CA-44

CO-SPONSOR



Rep. Earl Blumenauer

D-OR-03

CO-SPONSOR



Rep. Lisa Blunt Rochester

D-DE-01

CO-SPONSOR



Rep. Suzanne Bonamici

D-OR-01

CO-SPONSOR



Rep. Julia Brownley

D-CA-26

CO-SPONSOR



Rep. Sean Casten

D-IL-06

CO-SPONSOR



Rep. Emanuel Cleaver

D-MO-5

CO-SPONSOR

[View more](#) (10)

Quotes



Sen. Martin Heinrich

D-New Mexico

"Electrifying our homes and businesses is one of the surest climate actions that we can take right now. We can use already existing, proven technologies to dramatically reduce carbon pollution, create millions of good-paying jobs, and secure a more equitable future for our communities. The goal of ZEHA is to make the economic, environmental, and health benefits of electrification affordable and accessible to all Americans."



Rep. Paul Tonko

D-New York

"Decarbonizing our homes is one of the key challenges we will face in confronting the climate crisis. But building electrification also offers untapped opportunities to improve energy efficiency, spur innovation and provide homeowners with cleaner alternatives."



Rep. Kathy Castor

D-Florida

"All Americans deserve to live in homes that are good for their health, their pocketbooks, and the environment. This bill will help millions of families switch to cleaner electric appliances and save money on their utility bills, while also putting Americans to work in every hometown across the country."



Sen. Richard Blumenthal

D-Connecticut

"By incentivizing the purchase of clean electric appliances and shifting away from ones that pollute, the Zero Emissions Home Act will create jobs and put us on a smarter, sustainable path for the future."



Sen. Sheldon Whitehouse

D-Rhode Island

"This is something we can do right now to reduce our carbon footprint and get new, high-functioning appliances into homes."

[View more](#) (4)

Organizations



Evergreen Action

Sam Ricketts, Co-Founder

"The Zero-Emission Homes Act announced today by Senator Heinrich (NM) makes an essential investment in our nation's clean building infrastructure. Clean buildings that are carbon-free, affordable, and climate-ready are essential infrastructure and are a matter of survival for millions of Americans."



RMI

Mark Kresowik, Federal Policy Manager

"Senator Heinrich's proposal recognizes that the buildings where we live and work, and the appliances we use, are critical infrastructure that our nation must invest in to avoid the worst impacts of climate disruption and create healthier, safer, and more affordable homes and businesses."



Sunrun

Lynn Jurich, CEO

"The Zero-Emission Homes Act will turbocharge our efforts to decarbonize millions of homes across America – and will help create millions of good-paying jobs as we electrify everything to fight climate change. Sunrun commends Senator Heinrich for his pioneering and steadfast leadership on the clean energy transition."



Rewiring America

Ari Matusiak, CEO

"The climate part of the national infrastructure debate just got a lot more relevant to American families...The widespread job creation and the savings on utility bills that 85 percent of American households would immediately see are a potent political argument for this bill."

[View more](#) (246)

Let's #ElectrifyEverything. I pledge to electrify all the things in my life — and help make the case to electrify America.

Sign and you'll get:

- ✓ How to plug in to make a difference where you live
- ✓ Information on how to electrify your home
- ✓ The latest electrification news and updates

Email Address	ZIP Code	Phone (Optional)	I'm in

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Department of Energy – Weatherization Assistance Program (DOE, WAP) PY22 State Plan

APPLICATION FOR FEDERAL ASSISTANCE SF-424

Version 02

1. Type of Submission: ☐ Preapplication ☒ Application ☐ Changed/Corrected Application		2. Type of Application: ☒ New ☐ Continuation ☐ Revision		If Revision, select appropriate letter(s) Other (specify):
3. Date Received 12/13/2021		4. Applicant Identifier:		
5a. Fed Entity Identifier:		5b. Federal Award Identifier: DE-EE0009909		
State Use Only:				
6. Date Received by State: 12/13/2021		7. State Application Identifier:		
8. APPLICANT INFORMATION:				
a. Legal Name: State of Michigan				
b. Employer/Taxpayer Identification Number (EIN/TIN): 386000134		c. UEI: C2AQVDYYUAS7		
d. Address:				
Street 1: P.O. Box 30195 Street 2: 333 S Grand Ave City: Lansing County: INGHAM County State: MI Province: Country: U.S.A. Zip / Postal Code: 489097695				
e. Organizational Unit:				
Department Name: Michigan Department of Health and Human Services		Division Name: Bureau of Community Action & Economic Opportunity		
f. Name and contact information of person to be contacted on matters involving this application:				
Prefix: Ms First Name: Kris Middle Name: Last Name: Schoenow Suffix:				
Title: Bureau Director				
Organizational Affiliation: Michigan Department of Health and Human Services				
Telephone Number: 5173883085		Fax Number:		
Email: Schoenowk@michigan.gov				

APPLICATION FOR FEDERAL ASSISTANCE SF-424

Version 02

9. Type of Applicant:

A State Government

10. Name of Federal Agency:

U. S. Department of Energy

11. Catalog of Federal Domestic Assistance Number:

81.042

CFDA Title:

Weatherization Assistance Program

12. Funding Opportunity Number:

DE-WAP-0002022

Title:

2022 Weatherization Assistance Program

13. Competition Identification Number:

Title:

14. Areas Affected by Project (Cities, Counties, States, etc.):

Michigan - Statewide

15. Descriptive Title of Applicant's Project:

The Weatherization Assistance Program enables low-income families to permanently reduce their energy bills while making their homes more energy efficient, safe, and healthy.

APPLICATION FOR FEDERAL ASSISTANCE SF-424

Version 02

16. Congressional District Of:

a. Applicant: Michigan Congressional District 08

b. Program/Project: MI-Statewide

Attach an additional list of Program/Project Congressional Districts if needed:

17. Proposed Project:

a. Start Date: 07/01/2022

b. End Date: 06/30/2023

18. Estimated Funding (\$):

a. Federal	19,953,104.00
b. Applicant	0.00
c. State	0.00
d. Local	0.00
e. Other	0.00
f. Program Income	0.00
g. TOTAL	19,953,104.00

19. Is Application subject to Review By State Under Executive Order 12372 Process?:

- ☐ a. This application was made available to the State under the Executive Order 12372 Process for review
- ☒ b. Program is subject to E.O. 12372 but has not been selected by the State for review.
- ☐ c. Program is not covered by E.O. 12372

20. Is the applicant Delinquent On Any Federal Debt? (If "Yes", provide explanation)

No

21. By signing this application, I certify (1) to the statements contained in the list of certifications and (2) that the statements**

herein are true, complete and accurate to the best of my knowledge. I also provide the required assurances** and agree to

☒ I AGREE

** The list of certifications and assurances, or an internet site where you may obtain this list, is contained in the announcement or agency

Authorized Representative:

Prefix: Mr First Name: Daniel

Middle Name:

Last Name: Lance

Suffix:

Title: Financial Analyst

Telephone Number: 5172844255

Fax Number:

Email: lanced@michigan.gov

Signature of Authorized Representative: Signed Electronically

Date Signed: 05/26/2022

Authorized for Local Reproduction

Standard Form 424 (Revised 10/2005)
Prescribed by OMB Circular A-102

BUDGET INFORMATION - Non-Construction Programs

1. Program/Project Identification No. EE0009909		2. Program/Project Title Weatherization Assistance Program	
3. Name and Address State of Michigan P.O. Box 30195 Lansing, MI 489097695		4. Program/Project Start Date 07/01/2022	5. Completion Date 06/30/2023

SECTION A - BUDGET SUMMARY						
Grant Program Function or Activity (a)	Federal Catalog No. (b)	Estimated Unobligated Funds		New or Revised Budget		
		Federal (c)	Non-Federal (d)	Federal (e)	Non-Federal (f)	Total (g)
1. Federal	81.042	\$ 0.00		\$ 19,953,104.00		\$ 19,953,104.00
2.						
3.						
4.						
5. TOTAL		\$ 0.00	\$ 0.00	\$ 19,953,104.00	\$ 0.00	\$ 19,953,104.00

SECTION B - BUDGET CATEGORIES					
6. Object Class Categories	Grant Program, Function or Activity				Total (5)
	(1) GRANTEE ADMINISTRA TION	(2) SUBGRANTE E ADMINISTRA	(3) GRANTEE T&TA	(4) SUBGRANTE E T&TA	
a. Personnel	\$ 628,664.00	\$ 0.00	\$ 129,625.00	\$ 0.00	\$ 758,289.00
b. Fringe Benefits	\$ 461,515.00	\$ 0.00	\$ 88,138.00	\$ 0.00	\$ 549,653.00
c. Travel	\$ 70,600.00	\$ 0.00	\$ 68,400.00	\$ 0.00	\$ 139,000.00
d. Equipment	\$ 40,000.00	\$ 0.00	\$ 0.00	\$ 0.00	\$ 40,000.00
e. Supplies	\$ 30,000.00	\$ 0.00	\$ 0.00	\$ 0.00	\$ 30,000.00
f. Contract	\$ 200,000.00	\$ 1,496,483.00	\$ 2,535,229.00	\$ 400,000.00	\$ 18,369,317.00
g. Construction	\$ 0.00	\$ 0.00	\$ 0.00	\$ 0.00	\$ 0.00
h. Other Direct Costs	\$ 60,172.00	\$ 0.00	\$ 0.00	\$ 0.00	\$ 60,172.00
i. Total Direct Charges	\$ 1,490,951.00	\$ 1,496,483.00	\$ 2,821,392.00	\$ 400,000.00	\$ 19,946,431.00
j. Indirect Costs	\$ 5,532.00	\$ 0.00	\$ 1,141.00	\$ 0.00	\$ 6,673.00
k. Totals	\$ 1,496,483.00	\$ 1,496,483.00	\$ 2,822,533.00	\$ 400,000.00	\$ 19,953,104.00
7. Program Income	\$ 0.00	\$ 0.00	\$ 0.00	\$ 0.00	\$ 0.00

BUDGET INFORMATION - Non-Construction Programs

1. Program/Project Identification No. EE0009909		2. Program/Project Title Weatherization Assistance Program	
3. Name and Address State of Michigan P.O. Box 30195 Lansing, MI 489097695		4. Program/Project Start Date 07/01/2022	5. Completion Date 06/30/2023

SECTION A - BUDGET SUMMARY						
Grant Program Function or Activity (a)	Federal Catalog No. (b)	Estimated Unobligated Funds		New or Revised Budget		
		Federal (c)	Non-Federal (d)	Federal (e)	Non-Federal (f)	Total (g)
1.						
2.						
3.						
4.						
5. TOTAL		\$ 0.00	\$ 0.00	\$ 19,953,104.00	\$ 0.00	\$ 19,953,104.00

SECTION B - BUDGET CATEGORIES					
6. Object Class Categories	Grant Program, Function or Activity				Total (5)
	(1) PROGRAM OPERATIONS	(2) HEALTH AND SAFETY	(3) LIABILITY INSURANCE	(4) FINANCIAL AUDITS	
a. Personnel	\$ 0.00	\$ 0.00	\$ 0.00	\$ 0.00	\$ 758,289.00
b. Fringe Benefits	\$ 0.00	\$ 0.00	\$ 0.00	\$ 0.00	\$ 549,653.00
c. Travel	\$ 0.00	\$ 0.00	\$ 0.00	\$ 0.00	\$ 139,000.00
d. Equipment	\$ 0.00	\$ 0.00	\$ 0.00	\$ 0.00	\$ 40,000.00
e. Supplies	\$ 0.00	\$ 0.00	\$ 0.00	\$ 0.00	\$ 30,000.00
f. Contract	\$ 10,554,919.00	\$ 2,105,706.00	\$ 52,500.00	\$ 26,250.00	\$ 18,369,317.00
g. Construction	\$ 0.00	\$ 0.00	\$ 0.00	\$ 0.00	\$ 0.00
h. Other Direct Costs	\$ 0.00	\$ 0.00	\$ 0.00	\$ 0.00	\$ 60,172.00
i. Total Direct Charges	\$ 10,554,919.00	\$ 2,105,706.00	\$ 52,500.00	\$ 26,250.00	\$ 19,946,431.00
j. Indirect Costs	\$ 0.00	\$ 0.00	\$ 0.00	\$ 0.00	\$ 6,673.00
k. Totals	\$ 10,554,919.00	\$ 2,105,706.00	\$ 52,500.00	\$ 26,250.00	\$ 19,953,104.00
7. Program Income	\$ 0.00	\$ 0.00	\$ 0.00	\$ 0.00	\$ 0.00

BUDGET INFORMATION - Non-Construction Programs

1. Program/Project Identification No. EE0009909		2. Program/Project Title Weatherization Assistance Program	
3. Name and Address State of Michigan P.O. Box 30195 Lansing, MI 489097695		4. Program/Project Start Date 07/01/2022	5. Completion Date 06/30/2023

SECTION A - BUDGET SUMMARY						
Grant Program Function or Activity (a)	Federal Catalog No. (b)	Estimated Unobligated Funds		New or Revised Budget		
		Federal (c)	Non-Federal (d)	Federal (e)	Non-Federal (f)	Total (g)
1.						
2.						
3.						
4.						
5. TOTAL		\$ 0.00	\$ 0.00	\$ 19,953,104.00	\$ 0.00	\$ 19,953,104.00

SECTION B - BUDGET CATEGORIES					
6. Object Class Categories	Grant Program, Function or Activity				Total (5)
	(1) VEHICLES AND EQUIPMENT	(2) LEVERAGING	(3) Weatherization Readiness	(4)	
a. Personnel	\$ 0.00	\$ 0.00	\$ 0.00		\$ 758,289.00
b. Fringe Benefits	\$ 0.00	\$ 0.00	\$ 0.00		\$ 549,653.00
c. Travel	\$ 0.00	\$ 0.00	\$ 0.00		\$ 139,000.00
d. Equipment	\$ 0.00	\$ 0.00	\$ 0.00		\$ 40,000.00
e. Supplies	\$ 0.00	\$ 0.00	\$ 0.00		\$ 30,000.00
f. Contract	\$ 39,999.00	\$ 80,000.00	\$ 878,231.00		\$ 18,369,317.00
g. Construction	\$ 0.00	\$ 0.00	\$ 0.00		\$ 0.00
h. Other Direct Costs	\$ 0.00	\$ 0.00	\$ 0.00		\$ 60,172.00
i. Total Direct Charges	\$ 39,999.00	\$ 80,000.00	\$ 878,231.00		\$ 19,946,431.00
j. Indirect Costs	\$ 0.00	\$ 0.00	\$ 0.00		\$ 6,673.00
k. Totals	\$ 39,999.00	\$ 80,000.00	\$ 878,231.00		\$ 19,953,104.00
7. Program Income	\$ 0.00	\$ 0.00	\$ 0.00		\$ 0.00

DOE F 540.5
(08/05)

OMB Control No: 1910-5127
Expiration Date: 05/31/2023

U.S. Department of Energy
WEATHERIZATION ASSISTANCE PROGRAM
SUBGRANTEE INFORMATION
State: MI Grant Number: EE0009909 Program Year: 2022

Name:	Baraga-Houghton-Keweenaw CAA		Contact:	Mr. Paul Hannula	
			UEI:	JJ1TJNHFQJB9	
			DUNS:	153462288	
Address:	926 Dodge Street Houghton, MI 49931-0000		Phone:	(906) 482-5528	
			Fax:	(906) 482-5512	
			Email:	bhkcaawx@att.net	
Counties served:	BARAGA County KEWEENAW County HOUGHTON County	Tentative allocation: \$ 303,080.00 Planned units: 26 Type of organization: Non-profit organization Source of labor: Contractors	Congressional districts served:		CD MI-01

Name:	Blue Water Community Action		Contact:	Ms Marcie Goodwin	
			UEI:	UC52HNS3VJZ3	
			DUNS:	062876743	
Address:	302 Michigan St. Port Huron, MI 48060-0000		Phone:	(810) 455-6454	
			Fax:	(810) 982-7233	
			Email:	mgoodwin@bwcaa.org	
Counties served:	ST. CLAIR County	Tentative allocation: \$ 306,804.00 Planned units: 26 Type of organization: Non-profit organization Source of labor: Contractors	Congressional districts served:		CD MI-10

Name:	Capital Area Community Services Inc		Contact:	Mr. Bob Liss	
			UEI:	EH1KNVPD9GA9	
			DUNS:	076389618	
Address:	101 East Willow Street Lansing, MI 48906-0000		Phone:	(517) 393-1780	
			Fax:	(517) 393-6631	
			Email:	bliss@cacs wx.org	
Counties served:	CLINTON County EATON County SHIAWASSEE County INGHAM County	Tentative allocation: \$ 709,323.00 Planned units: 61 Type of organization: Non-profit organization Source of labor: Contractors	Congressional districts served:		CD MI-08 MI-04 MI-07

Name:	Chippewa-Luce-Mackinac Community Action and		Contact:	Ms. Jessica Johnston	
			UEI:	G4TEAHYL63E6	
			DUNS:	116103888	
Address:	P. O. Box 70 524 Ashmun Street Sault Ste Marie, MI 49783-0000		Phone:	(906) 632-3363	
			Fax:	(906) 632-4255	
			Email:	jjohnston@clmcaa.com	



Inequitable access to distributed energy resources due to grid infrastructure limits in California

Anna M. Brockway^{1,2}, Jennifer Conde³ and Duncan Callaway^{1,2}✉

Persistent social disparities in the adoption of distributed energy resources (DERs) have prompted calls for enabling more equitable uptake. However, there are indications that limits inherent to grid infrastructure may hinder DER adoption. In this study we analysed grid limits to new DER integration across California's two largest utility territories. We found that grid limits reduce access to solar photovoltaics to less than half of households served by these two utilities, and may hinder California's electric vehicle adoption and residential load electrification goals. We connected these results to demographic characteristics and found that grid limits also exacerbate existing inequities: households in increasingly Black-identifying and disadvantaged census block groups have disproportionately less access to new solar photovoltaic capacity based on circuit hosting capacity. Our results illuminate the need for equity goals to be an input in the design of policies for prioritizing grid upgrades.

Electricity systems are undergoing the most fundamental shifts since their inception. As with any transition, benefits and burdens may fall unequally, and some may be left behind^{1,2}. A growing body of literature has documented persistent social disparities in customer adoption of distributed energy resources (DERs), with a particular focus on behind-the-meter solar photovoltaic (PV) systems. Residential PV adoption patterns have perpetuated financial^{3–5}, racial⁶ and cumulative⁷ inequities, even beyond those stemming from the typical requirements of owner-occupied households with favourable site characteristics^{8–10}. In response, federal and state programmes intended to support more equitable uptake have emerged^{3,6,11}.

The distribution grid's ability to accommodate new PV systems depends on where and how they interconnects^{12–14}. As deployment increases, grid limits will hinder new connections, leading to costly project delays^{15–17} or interconnection denials¹⁸, and/or necessitate circuit upgrades^{19,20}. As we near the limits of DER deployment that the existing distribution equipment can accommodate, policymakers and regulators will need to establish criteria for which grid upgrades are worth increasing customer rates. If grid limits are not considered, further inequities may emerge.

To our knowledge, no systematic analyses have yet considered how equitably the existing grid can accommodate DERs. Studies of equity in PV deployment have focused on previous or existing adoption^{4–7}, rather than what the future may hold. Researchers evaluating grid capacity for DERs have focused on technical circuit models or isolated case studies rather than full electric grids, and have not considered customer demographics^{14,21–25}. There is, therefore, a gap in our understanding of how grid limits within and across utility territories may impact future DER deployment, and the potential implications for equity and access to DERs. We do not ascribe causation to lower hosting capacity in certain communities. Rather, we strive to document disparities so that future policies do not exacerbate patterns of inequity and may even improve the state of affairs.

In this study we investigated the magnitude and distribution of electric grid constraints for DERs on circuits operated by California's two largest investor-owned utilities (IOUs), Pacific Gas and Electric (PG&E) and Southern California Edison (SCE), which together

serve over 30 million people. We focused on identifying where constraints may limit DER growth and asked whether they may differentially impact demographic groups. We found that the distribution grid restrains households' ability to adopt DERs across these two IOU territories, and that hosting capacity is unevenly distributed. When all grid constraints were considered, we found that over half of residential households served by PG&E and SCE (57 and 59%, respectively) lack adequate hosting capacity for 4.5 kW of solar PV, the amount required to offset 100% of their annual electricity consumption, on average. In PG&E's territory, 39% of households lack access to even the least power-intensive new loads (space and water heating or level 1 electric vehicle (EV) charging), while 64% lack access to level 2 EV charging. Notably, hosting capacity for DERs decreases for households in increasingly Black-identifying and disadvantaged communities. Correlations between hosting capacity and race are the starkest among a variety of demographic indicators analysed, including those relating to income, housing characteristics and education. We do not make causal claims but seek to illuminate important correlations that exist in the data, which here include disparate access to grid resources falling along lines of race. This work points to the need for grid planners everywhere to analyse the equity of electrical capacity for DER adoption and demonstrates a way to do this. Such an analysis should be an input to planned grid upgrades so that the grid itself does not become a limitation to equitable DER uptake in the future.

Growth in DERs raises issues for equity and the grid

We were motivated here by two separate and robust sets of findings in the literature: that there exist inequities in DER adoption and that the electric distribution grid itself imposes limits on where DERs can interconnect. We considered how grid limits may impede continued DER deployment and assessed how they overlap with customer demographics. In doing so, we have built on the existing literature by (1) considering the importance of technical grid limits, which have largely been ignored in previous work on equity in DER adoption, and (2) using those grid constraints to consider the future equities of DER deployment, whereas others have focused on existing adoption.

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A rich literature has emerged concerning the inequities of solar PV adoption. Despite similar motivations for adopting solar²⁶, low- and moderate-income (LMI) communities experience disproportionately low PV penetration rates^{3–5}, even where there is relatively high potential for solar³. While policies designed to foster more equitable uptake have made a difference¹¹ and middle-income households have slowly increased their relative share of PV⁴, low- and moderate-income households still lag behind.

Minority households are disproportionately vulnerable to energy poverty in the United States²⁷. Yet PV adoption, which can reduce household electricity bills, skews to white-majority census tracts⁶. When multiple inequities are considered, persistently lower adoption is found in disadvantaged communities⁷, as measured by the metrics in California's CalEnviroScreen indicator, which was developed to reflect the cumulative impact of environmental, socioeconomic and public health stresses²⁸.

Socioeconomic factors have also been found to influence EV adoption²⁹. Yet just as the electric grid is a necessary enabling resource for DERs, public charging is an enabling technical resource for EV ownership, and public charging access is less widespread in low-income and minority communities³⁰.

To date DER deployment has perpetuated social inequities, and in the future, electric grid limits may constrain DER growth. Electric power systems in the United States were designed to rely on centralized power sources, but DERs, such as solar PV and EVs, now contribute growing shares of electricity supply and demand. Well-sited DERs can defer capacity upgrades¹⁴, boost sagging line voltages, and reduce power losses³¹. However, DERs can also disrupt circuit protection schemes, increase thermal loading, cause overvoltages and create dangerous islanding conditions^{32,33}.

These grid impacts arise from increased current flow beyond what local equipment can handle. They may be avoided if both generation and load DERs are sited in the same location and their operation is synchronized in time; however, even if they complement each other on average, operating variations due to customer behaviour and weather will necessitate storage or demand response to fully defer system constraints. As these technologies are not mandated in California today, we have left this nuance to follow-on work and focused here on where DERs may connect to distribution circuits without necessitating complementary technologies.

The hosting capacity is the allowable capacity of DERs that an electric circuit can accommodate without upgrades. Calculating hosting capacity is not straightforward and several methodologies have emerged^{34–36}. They differ in which circuit constraints are considered and which numerical methods are used to calculate violations (see Supplementary Note 1 for details). In California, hosting capacity information is available through Integration Capacity Analysis (ICA) maps, which also include data on existing distributed generation^{37,38} (Supplementary Note 2). Hosting capacity values include the additional PV and load capacities that can be connected to a line segment without violating thermal, power quality/voltage or protection constraints³⁷. PV capacity is reported with operational flexibility (OpFlex; in which case reverse power flow is not allowed beyond the substation bus) and without OpFlex (in which case reverse flow is allowed) constraints³⁷.

In this study we assessed how grid constraints may impact the equity of DER access. California offers a ripe case study of the implications of employing DERs to expand clean energy capacity. Aggressive policies and a responsive market have helped California lead the nation in PV capacity and EV adoption (Supplementary Note 3). Behind-the-meter PV comprised almost 30% of the state's solar PV capacity at the end of 2019³⁹, and is expected to remain a major category of renewables deployment due to a diversity of supporting policies^{40,41}. Substantial economic benefits are available to California households that adopt rooftop solar⁴². In this context, disparate rates of access (whether due to structural or grid limits)

are important, and we assessed here the extent to which making access to renewable energy specific to the location of one's home and the circuit to which it is connected may strain California's access and equity goals.

Despite documented inequities in current deployment, all ratepayers currently pay for the grid upgrades necessary to accommodate projected DER growth. Upgrade decisions have been based in part on historic deployment patterns, and SCE estimates that it will cost US\$14–44 million annually from 2021 to 2023 to reinforce its circuits for DERs⁴³.

In California, small DERs have so far been allowed to bypass interconnection study requirements¹⁹. However, state regulators have indicated that hosting capacity values may be considered in future DER interconnection rules to avoid violating location-specific penetration limits^{37,38,44}. Future grid upgrades with socialized costs, therefore, are not a guarantee. Policies that seek to address inequities in DER deployment will need to consider the limits imposed by the electric grid as it exists today, or investments associated with upgrading it.

Grid limits reduce access to DERs across utility territories

We calculated the proportion of households with DER access at deployment thresholds in the range 1.5–10.0 kW per household to account for varying capacity estimates for PV and load DERs (see Methods), for each DER type and for each census block group (CBG) within each utility territory (see Eqs. (14) and (15) in Methods). We found that per-household hosting capacity for load and generation DERs (Supplementary Note 4) varies widely across the PG&E and SCE service territories (Fig. 1 and Extended Data Figs. 1–3). We present the results for household access within each full utility territory and summary statistics by CBG in Figs. 2 and 3 (see Supplementary Tables 1–3 and Supplementary Figs. 1 and 2 for selected values and full results). The PG&E results pertain only to those sections of the territory with ICA data.

We found that the constraints on distributed generation limit how much PV can be deployed on distribution circuits in California. Due to thermal, power quality and protection grid constraints, 31 and 25% of households in the PG&E and SCE territories, respectively, lack access to 4.5 kW of behind-the-meter PV (which is, on average, enough to balance 100% of annual electricity usage). These values consider both the existing generation already deployed on circuit lines as well as remaining hosting capacity. With OpFlex constraints, substantially more households, approximately 57 and 59% served by PG&E and SCE, respectively, lack access to 4.5 kW of rooftop PV. Therefore, under current grid conditions, sufficient capacity exists for less than half of households to adopt PV.

These numbers are highly sensitive to the deployment threshold used (Fig. 2). More households can adopt smaller PV sizes, although 23% (16% if OpFlex constraints are disregarded) in both territories still lack access to even 1.5 kW. At 10 kW, 78 and 79% of PG&E and SCE households, respectively, lack access (49 and 38% if OpFlex constraints are disregarded).

Fewer households can adopt PV if only remaining hosting capacity is considered. Approximately 77 and 70% of households served by PG&E and SCE, respectively, then lack access to solar (41 and 30% if OpFlex constraints are disregarded). This observation illustrates a tension around equitable deployment: if grid capacity is occupied by early adopters, efforts to improve equity in PV adoption may be caught in a race with continuing adoption among already well-represented demographic groups for the circuit hosting capacity that remains.

Physical building suitability may further reduce household access: based on data generated by previous researchers^{9,10}, we estimate that approximately 15% of small buildings in PG&E's territory and 9% in SCE's territory cannot host 1.5 kW of PV (Fig. 3). When combined with grid limits, the proportion of households lacking

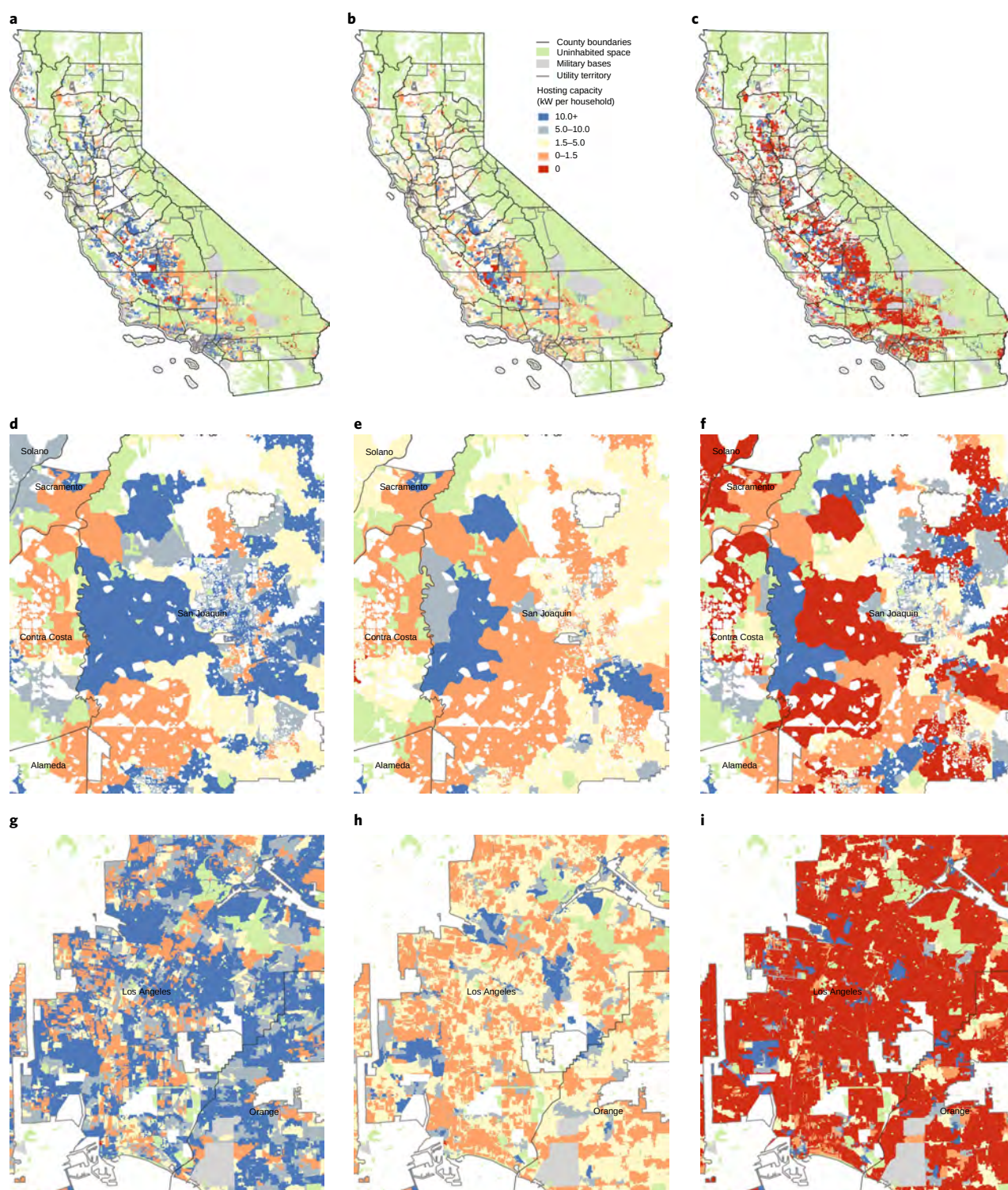


Fig. 1 | Household access varies by DER type and location. **a–i**, Per-household hosting capacity for PV (**a,d,g**), PV with OpFlex (**b,e,h**) and load (**c,f,i**) across the PG&E and SCE service territories (**a–c**), a portion of PG&E's service territory, including parts of San Joaquin County (and the city of Stockton; **d–f**), and a portion of SCE's service territory, including parts of Los Angeles and Orange counties (**g–i**). The code for the different colours and lines shown in all the maps is given in **b**. White areas indicate regions served by other utilities or, within PG&E's territory, locations with no ICA data. High-resolution versions of these maps are available in Extended Data Figs. 1–3 and at <https://github.com/Energy-MAC/GridLimitsforDERs>.

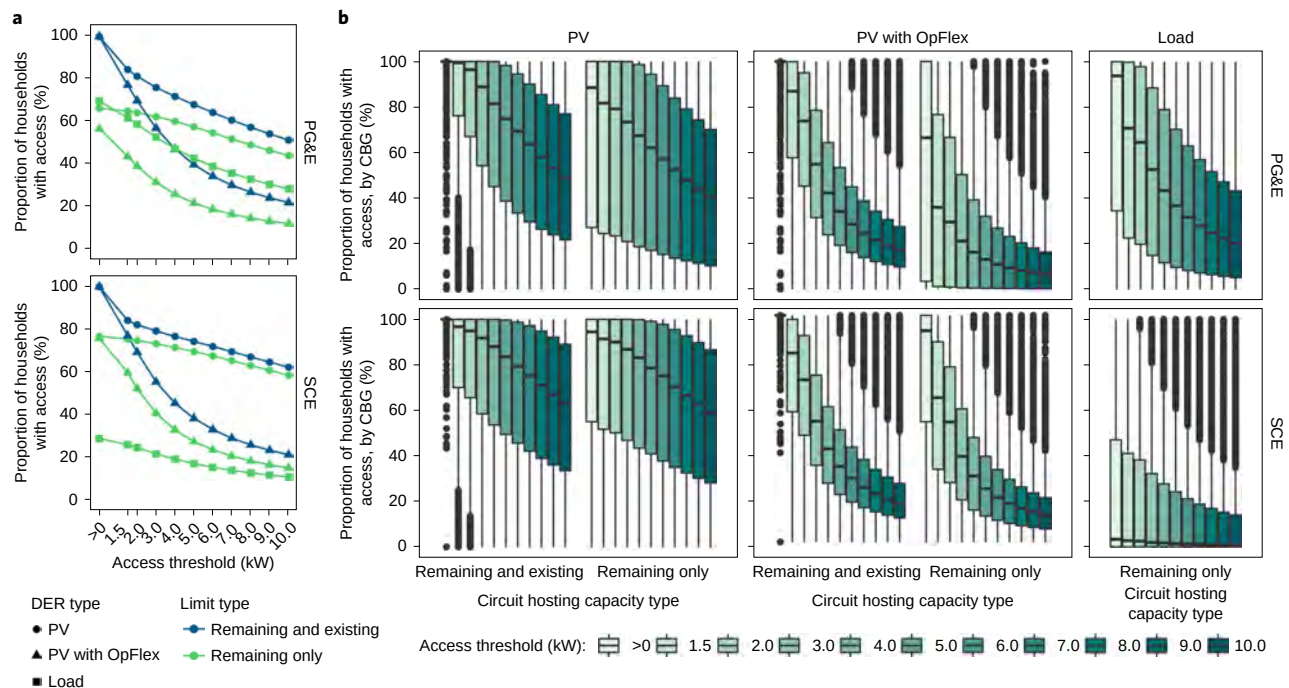


Fig. 2 | Results for household access to PV and load DERs. **a**, Access to PV and load DERs for all households within the PG&E and SCE utility territories. **b**, Boxplots showing hosting capacity at different access thresholds for each CBG included in the data. Each boxplot shown for PG&E represents 2.13 million households across 7,996 CBGs (this is less than the total number of households served by PG&E due to a lack of available ICA data for all circuits), and each boxplot shown for SCE represents 4.15 million households across 8,376 CBGs. All boxplots show the 25th, 50th and 75th percentiles of access results, with whiskers extending to the furthest point within 1.5 times the interquartile range. Further points are shown as outliers.

access to 1.5 kW of behind-the-meter PV increases, in PG&E's territory, from 16 to 27–30% under the worst- and best-case scenarios for combined suitability. In SCE's territory, the proportion of households lacking access increases from 16 to 23–25%. Similar declines in access occur for the OpFlex case.

We also found that constraints on load may challenge the adoption of EVs and electrification technologies. The grid may require upgrades to meet electrification goals and air-conditioning needs; otherwise, it could hinder climate change mitigation and adaptation⁴⁵ efforts in California. However, the extent to which load DERs will stress the distribution grid requires further research. While ICA maps show hosting capacity by circuit segment for generation and load, IOU circuit analyses have so far focused on generation. Load information, particularly in SCE's territory, may systematically underestimate circuit hosting capacity⁴⁶. Moreover, existing load analyses are technology-agnostic and IOUs could improve data interpretability by including analyses of specific load DERs, including EVs, air conditioning and heat pumps for space and water heating, which all have time-varying use profiles.

Based on currently available load data, widespread adoption of even the least power-intensive applications could strain distribution grids. Using a 1.5 kW demand threshold to analyse access to space and water heaters (together 1.6 kW) and level 1 EV charging (1.4–1.9 kW), we estimate that 39 and 74% of households served by PG&E and SCE, respectively, lack sufficient grid capacity for either electrified heating or EV charging (Fig. 2a). In PG&E's territory, 64% of households lack the grid access to install a level 2 EV charger.

If households implement all the climate change mitigation strategies that we considered, namely the conversion of natural gas-powered space and water heaters to electric, EV level 2 charging and new air-conditioning units, hosting capacity will be severely limited (Fig. 2). Although the full extent of distribution grid impacts

from increasing load is not yet known, it is clear that the grid cannot currently accommodate fully electric homes across the state.

Grid limits reinforce demographic disparities in DER access

Variations in access across utility territories prompted us to consider how hosting capacity may be correlated with variables related to infrastructure, service, geography and demographics (see Supplementary Tables 6–8 and Supplementary Note 9 for variable descriptions). We were particularly interested in whether differences in hosting capacity may reflect demographic variations. We constructed linear and non-linear models to understand which variables, if any, may correlate to per-household hosting capacity. The model results indicate that no single demographic feature dominates in relative importance over the rest (see Supplementary Note 5 and Supplementary Fig. 3 for a full discussion). However, we did find notable relationships between consumer demographics and access to circuit capacity. In examining these, we focused on the demographic categories discussed in prior literature on DER adoption.

First, we validated our approach by examining the relationships between demographic indicators and existing distributed generation, and found that our results broadly support previous findings. For race and ethnicity, we observed higher median levels of existing distributed generation per household in CBGs with more non-Latinx white- and Latinx-identifying populations than Black- or Asian-identifying populations (Fig. 4a). For CBGs with more Black- and Asian-identifying populations, very few households are represented at higher percentages, leading to wide confidence intervals and indefinite trends above approximately 50%. Existing generation per household also declines overall with increasing diversity in the population. For disadvantaged communities (as defined in CalEnviroScreen²⁸), we found stronger correlations between

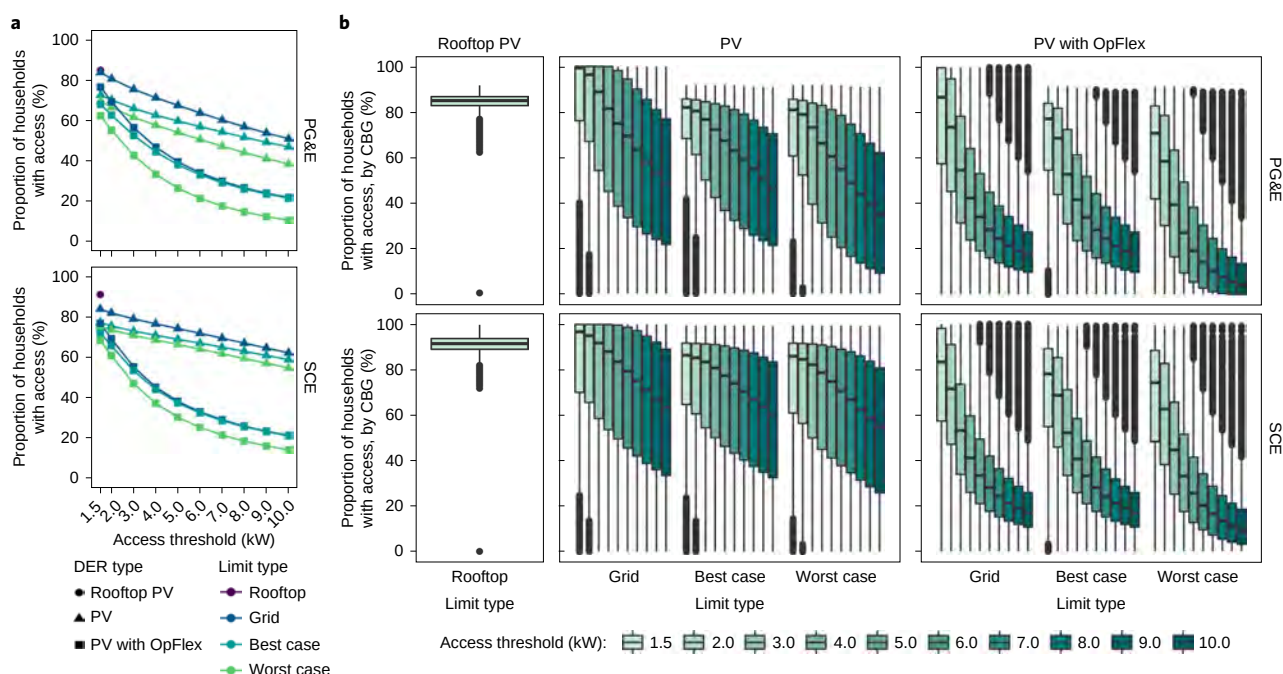


Fig. 3 | Results for household access to PV DERs considering grid (remaining plus existing capacity) and building suitability limits. a, Access to PV DERs for all households within the PG&E and SCE utility territories. **b**, Boxplots showing hosting capacity at different access thresholds for each CBG included in the data. Each boxplot shown for PG&E represents 2.13 million households across 7,996 CBGs (this is less than the total number of households served by PG&E due to a lack of available ICA data for all circuits), and each boxplot shown for SCE represents 4.15 million households across 8,376 CBGs. All boxplots show the 25th, 50th and 75th percentiles of access results, with whiskers extending to the furthest point within 1.5 times the interquartile range. Further points are shown as outliers. We note that building suitability estimates are available only for 1.5 kW PV systems⁶⁵. The combined suitability at higher access thresholds (2–10 kW) was calculated assuming the higher threshold for grid limits, but still a 1.5 kW threshold for building suitability. This underestimates the contribution of building suitability to PV deployment limits at thresholds above 1.5 kW, while overestimating the proportion of households with access.

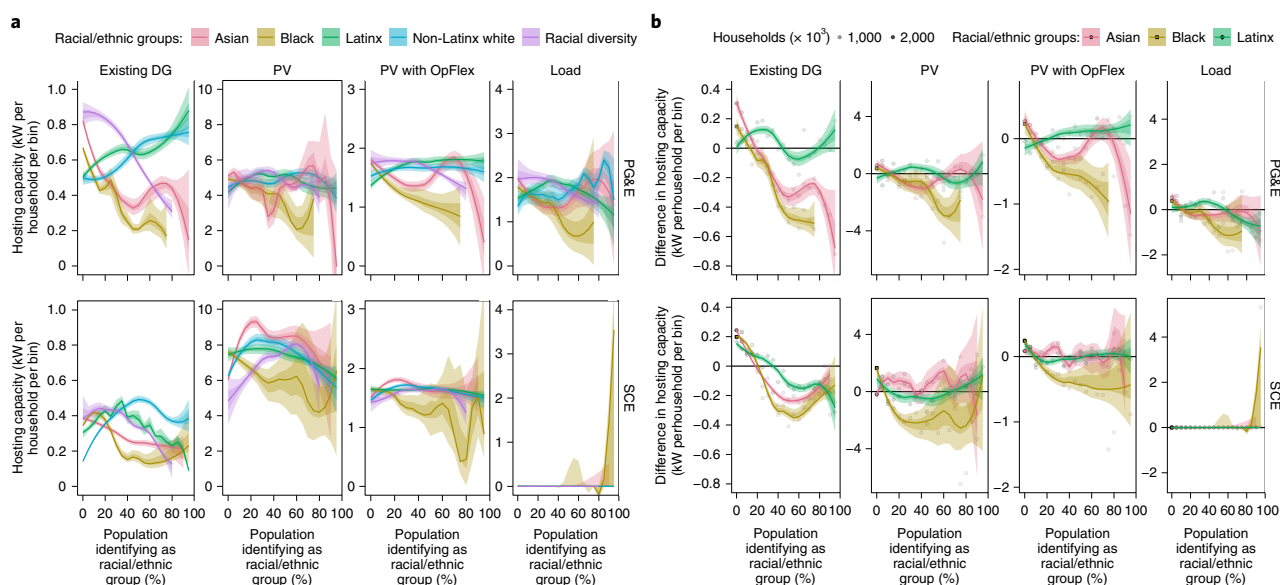


Fig. 4 | Hosting capacity results for race and ethnicity variables. a, Median existing generation or hosting capacity by race and ethnicity. **b**, Difference in median existing generation or hosting capacity between different racial and ethnic groups and the non-Latinx white population. The confidence intervals shown are 50% (darker band) and 90% (lighter band).

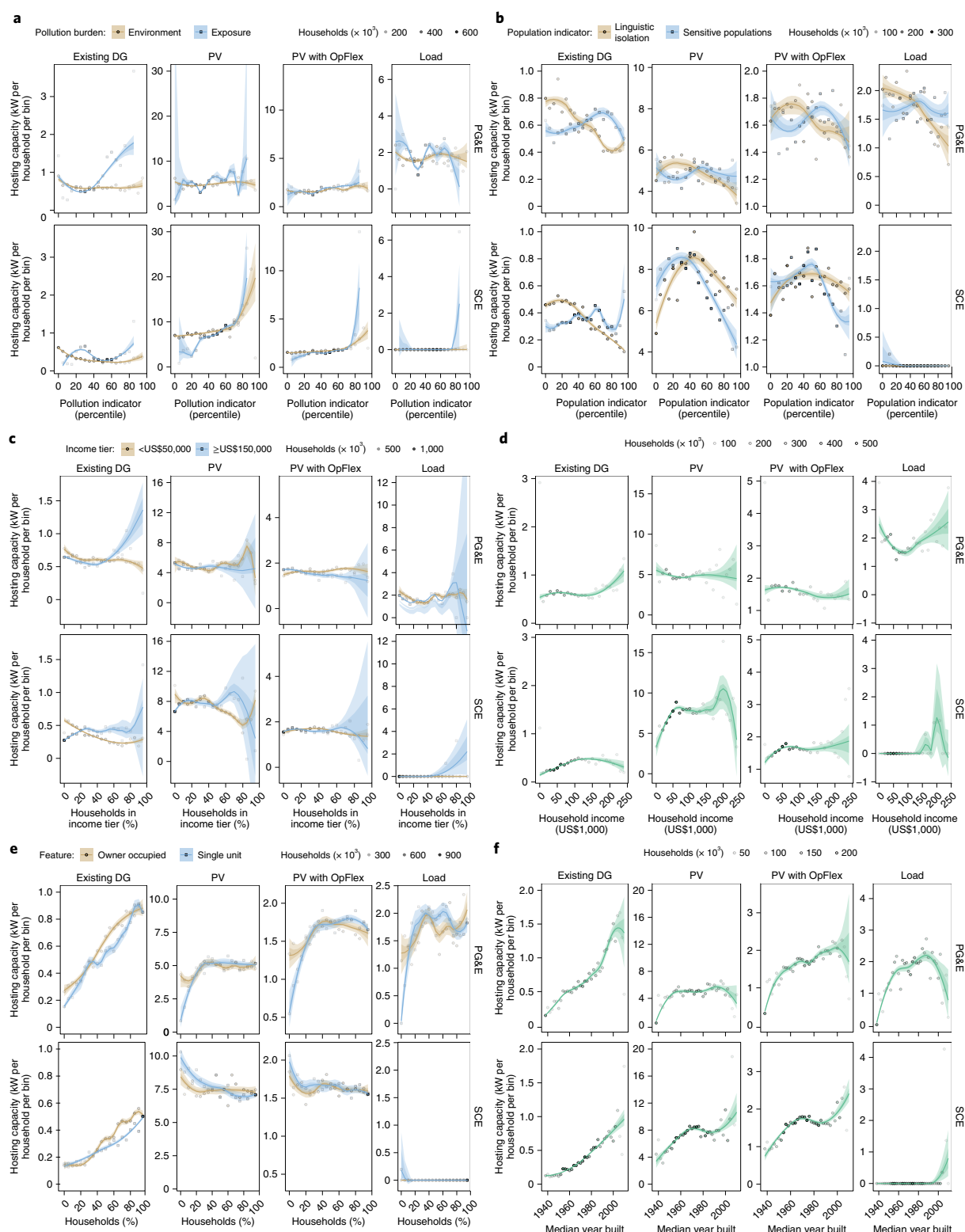


Fig. 5 | Hosting capacity for additional demographic variables. **a, b**, Median existing generation or hosting capacity for the CalEnviroScreen indicators of pollution (**a**) and population (**b**). **c, d**, Median existing generation or hosting capacity for income variables, analysing the proportions of the poorest and wealthiest households (**c**) and the median household income (**d**). **e, f**, Median existing generation or hosting capacity for housing characteristics, considering the proportions of single-unit and owner-occupied households (**e**) and median year of house build (**f**). The confidence intervals shown are 50% (darker band) and 90% (lighter band).

Table 1 | Independent variable groups for random forest regression and classification runs

Variable group	Description	Examples
(1) All	All variables included in any of the other three groups	–
(2) Infrastructure	Variables that describe characteristics of electricity infrastructure, sourced from PG&E and SCE directly	Nominal circuit voltage, circuit line lengths
(3) Service and geography	Variables that pertain to how electric infrastructure serves customers and the environmental conditions it is exposed to	Households per circuit polygon and kilometre of circuit length, number and percentage of residential customers served by each circuit, solar irradiance and heat metrics
(4) Demographic	Variables obtained from the American Community Survey ⁶² and CalEnviroScreen ²⁸	Percentage of population identifying as specific racial and ethnic groups and within specific income tiers, median household income, residential structure characteristics

A full list of variables in each category can be found in Supplementary Tables 6–8.

existing distributed generation and population metrics (measures of sensitive population and linguistic isolation, Fig. 5b) than pollution metrics (Fig. 5a; similar to Lukanov and Krieger⁷), most notably for the percentile of linguistic isolation in the population, which could reflect an information barrier to DER adoption. For income, our analysis supports previous findings that wealthier communities are more likely to have already installed DERs^{4,5}. This effect broadly holds for the poorest and wealthiest CBGs (Fig. 5c), as well as the median household income (Fig. 5d), with some drop-off for data points representing fewer households. Finally, as expected for types of housing^{8–10}, existing generation capacity increases sharply with the percentage of owner-occupied and single-unit households, as well as with the median year of construction for residential housing (Fig. 5e,f).

Then, we extended our analysis to consider how total circuit hosting capacity for PV (existing plus remaining) and load (remaining capacity only, focusing on PG&E) correlates with these same demographic indicators.

With respect to race and ethnicity, we found that the total circuit capacity for generation decreases with increasing percentages of Black-identifying residents, and is disproportionately lower for CBGs with Black-identifying populations than for other racial and ethnic groups. Specifically, the trends in total circuit capacity for PV, with and without OpFlex constraints, show a notably lower capacity in Black-identifying CBGs than in non-Latinx white-, Latinx- and Asian-identifying CBGs for both utilities. To better see these differences, we plotted locally estimated scatterplot smoothing (LOESS) curves for the difference in median existing generation and hosting capacity between non-Latinx white-identifying population percentages and the other racial and ethnic groups (Fig. 4b). While the differences with Latinx- and Asian-identifying CBGs are small, the total circuit capacity is substantially lower for Black-identifying CBGs and largely decreases as Black-identifying percentages increase. This suggests that distribution circuits cannot currently support the same PV deployment, whether or not OpFlex constraints are active, in neighbourhoods with higher Black populations relative to other racial and ethnic groups. Circuit capacity values for remaining load are less interpretable (see the discussion above), but we see here that, in the PG&E territory, less circuit

capacity is available with increasing percentages of Black-identifying residents than for other races.

Disadvantaged communities, as identified by the CalEnviroScreen sensitive and linguistically isolated population indicators²⁸, also experience inequitable circuit capacity for PV deployment. Some of the starkest trends occur for the population indicators: median generation hosting capacity decreases with sensitive populations above the 50–60th (for PG&E) and 30–50th (for SCE) percentiles, and decreases with linguistic isolation above the 20th (for PG&E) and 40th (for SCE) percentiles (Fig. 5b). The most disadvantaged populations in the state therefore face systematically lower circuit hosting capacity for PV. Opportunities for future DER deployment, especially of technologies that can shift electricity consumption patterns, such as solar plus storage, may be particularly salient for these communities⁴⁷, which tend to bear disproportionate local pollution impacts from California's natural gas peaker plants⁴⁸.

Income trends for circuit capacity are less consistent, suggesting that income variations are insufficient for explaining the relationships between circuit capacity and Black-identifying and disadvantaged communities. For the poorest households, the clearest trends are found in SCE's territory, where the hosting capacity for PV tends to decline slightly with increasing proportions of poor households. As the proportion of wealthy households increases, the total circuit capacity shows a slightly downward tendency in PG&E's territory, but stays relatively flat in SCE's territory (Fig. 5c). Above the 80th percentile, wide divergences in data are observed due to relatively few households falling into the highest-income bins. The circuit capacity for PV largely declines with median household income in PG&E's territory (excepting some values representing relatively few households in high-income brackets), but increases with median income up to approximately US\$100,000 in SCE's territory (Fig. 5d). These mixed results suggest that the clearer trends for racial and ethnic groups and CalEnviroScreen population indicators are not driven by underlying income distributions.

Housing characteristics also show mixed results. The total circuit hosting capacity for generation and load tends to increase with single-unit and owner-occupied percentages in PG&E's territory, although plateauing earlier than for existing generation, while assuming the inverse trends in SCE's territory (Fig. 5e). For both utilities, the total circuit hosting capacity for generation tends to increase with year of construction (Fig. 5f); median housing age may correlate with the age of local grid infrastructure. In PG&E's territory, areas with the newest buildings have less hosting capacity than slightly older buildings.

Our key results are broadly consistent across both utility territories. The most notable differences between customers served by the two utilities pertain to the relative proportions of non-Latinx white- and Latinx-identifying populations, and residents' pollution exposure (Supplementary Fig. 6 and Supplementary Note 7). These demographic indicators do not show strong trends in our results.

This work enables us to consider where inequities may be exacerbated in the future. As net-metered solar frequently carries tangible benefits for its adopters, including an attractive economic proposition⁴² and more stable electricity bills, these inequities run the risk of limiting its benefits along demographic lines.

Conclusions

Taken together, our results indicate that grid limits pose constraints for future DER deployment across utility territories and may exacerbate existing inequities related to DER adoption. With all grid constraints enforced, over half of households served by PG&E and SCE (57 and 59%, respectively) lack grid access to adopt sufficient PV to offset their annual electricity consumption, on average. If we consider only remaining circuit hosting capacity, up to three-quarters of households served by PG&E and SCE (77 and 70%, respectively)

lack access. As existing PV adoption has tended to skew towards wealthier, whiter and less-disadvantaged households, these results raise concerns that the grid may hinder efforts to increase equity in DER adoption.

Grid capacity may also limit the amount of new load that can be added to residential distribution circuits through electrification programmes, EV adoption or increased air-conditioning demands. In PG&E's territory, 39% of households lack access to even the least power-intensive new loads (space and water heating or level 1 EV charging), while 64% lack access to level 2 EV charging. Household access results are sensitive to the size capacity of the DERs deployed per household and, for generation, to whether OpFlex constraints are enforced.

Furthermore, we have found important disparities in household access by demographic characteristics that are consistent with disparities in existing PV capacity. Median per-household circuit capacity for DERs is lower for CBGs with higher Black-identifying populations than other racial and ethnic groups, and decreases with rising proportions of Black-identifying residents. Grid capacity for DERs also decreases for more disadvantaged communities, as measured by the CalEnviroScreen sensitive and linguistically-isolated population indicators.

In this work we sought to document existing patterns in circuit hosting capacity and their potential impacts on access to DERs. Our primary aim was to illuminate these patterns for consideration in future grid planning and policy. However, we do offer two hypotheses about how the disparities we report could have come to pass. First, we know that circuit upgrades to accommodate DERs have already occurred, and are continuing to occur, on some circuits⁴³. It is possible that those upgrades may have enabled excess hosting capacity beyond what was needed for the DERs that prompted them. If those upgrades have occurred in neighbourhoods that tend to be early adopters of DERs, that could have inadvertently led to more hosting capacity in areas populated by early adopters. Second, circuits designed for areas where additional housing development was expected to occur may have been built with excess capacity that could translate to more hosting capacity for DERs today. It is possible that these areas of projected housing expansion could correlate to certain demographic characteristics. Testing either of these hypotheses would require data that we do not have and that may not exist. Therefore, we offer these to share possible explanations for how social disparities in these engineered systems could have arisen, not to indicate how they did.

Notably, we have assessed the grid limits for generation and load DERs in isolation. If their operation is synchronized in time and space, these technologies could complement each other and reduce their impact on the grid. To accomplish this, policy requiring co-located storage or demand response would be required, and evaluating the potential impacts of this is a potential direction for future work.

To meet its decarbonization goals, the State of California will need to make tremendous investments in grid capacity, which will require both time and money to implement. Our results illuminate that current policy promoting site-specific distributed generation may face obstacles to equity from physical systems, including those that fall along racial lines. Enabling all distribution circuits in the state to host adequate DER capacity for desired generation and electrification needs will not happen simultaneously without massive investment in staff and resources. Currently, SCE prioritizes distribution circuits for upgrades that are intended to boost hosting capacity on the basis of projected DER deployment. Yet targeting grid investments could reduce existing inequities. For example, there is an opportunity to put at the front of the queue communities with historically low DER adoption rates who are served by distribution circuits with low available hosting capacity.

Remaining hosting capacity will decrease as more households adopt PV and EVs, electrify heating loads and opt to acquire or operate air conditioners, and electric distribution systems will draw closer to their limits, potentially creating obstacles to timely and equitable DER access. Nationwide and elsewhere, policymakers and regulators will increasingly confront grid limits as a barrier to renewable energy adoption. Evaluating the implications of these limits will be critical to reaching equity goals for the deployment of distributed energy resources.

Methods

Residential households are matched to distribution circuits. In this study we used recent advances in electric distribution grid data availability in the State of California. To begin, we matched residential customers to PG&E and SCE distribution circuits. Our goal was to estimate where residential utility customers live and which circuit lines provide them with electric service. Our analysis relied on two key assumptions. First, we assumed that residential customers are evenly distributed within the potentially inhabited areas of each CBG, which we estimated here to be those areas that are not protected open space (for example, parks or wilderness areas) or military bases. We also assumed, similar to a study included in California's Fourth Climate Change Assessment (CCCA4) report⁴⁹, that electricity customers are served by their nearest electric system equipment. Here, this means residential customers are grid-connected to the nearest distribution circuit segment.

All spatial processing was conducted in ArcGIS 10.6⁵⁰ in coordinate system NAD 1983 California Teale-Albers⁵¹. Starting with the CBGs⁵², we erased areas that comprise protected open space^{53,54} and military bases⁵⁵ to exclude them from consideration, leaving us with potentially inhabited land area. For each CBG, we calculated:

$$\text{InhArea\_Wt}_i = \frac{\text{InhArea}_i}{\text{OrigArea}_i} \quad (1)$$

where OrigArea_i is the original area of block group i and InhArea_i is its potentially inhabited area (both in m^2), and InhArea_Wt_i is the proportion of the original area that is potentially inhabited. Then, we clipped the potentially inhabited areas of the CBGs by the PG&E and SCE utility territory boundaries⁵⁶. For each block group located fully or partially within each utility's territory, we calculated:

$$\text{IOUarea\_Wt}_i = \frac{\text{IOUarea}_i}{\text{InhArea}_i} \quad (2)$$

where IOUarea_i is the portion of block group i 's potentially inhabited area located within the IOU's territory (m^2 ; for example, Supplementary Fig. 4a), and IOUarea_Wt_i is the portion of the potentially inhabited area that falls within the IOU's territory.

We then used the Euclidean Allocation tool of ArcGIS to assign 10 m^2 grid cells to their nearest one-, two- or three-phase circuit segment. (Using PG&E's feeder data⁵⁷ and SCE's customer type data⁵⁸, we excluded circuits that serve fewer than 1% residential customers.) We converted the raster output to simplified polygons to produce smooth boundaries. We obtained polygons that mimic a Voronoi tessellation, but are formed around line segments rather than point locations (for example, of substations, as in the CCCA4 study⁴⁹).

Next, we performed a union of these circuit-segment polygons with the CBGs. We combined the resulting features by circuit name to create circuit polygons that describe spatial areas that are unique combinations of (1) the service area for a given circuit j and (2) a given CBG i . For each circuit polygon we calculated:

$$\text{CpolyA\_Wt}_{ij} = \frac{\text{CpolyA}_{ij}}{\text{IOUarea}_i} \quad (3)$$

where CpolyA_{ij} is the area (m^2) served by circuit j within block group i and CpolyA_Wt_{ij} is the portion of the block group's potentially inhabited area that circuit serves within the IOU's territory (Supplementary Fig. 4b).

This approach allowed us to calculate the estimated number of customers served by electric distribution lines within each circuit polygon:

$$\text{tothh\_Cpoly}_{ij} = \text{tothh\_bg}_i \times \text{IOUarea\_Wt}_i \times \text{CpolyA\_Wt}_{ij} \quad (4)$$

$$\text{totpop\_Cpoly}_{ij} = \text{totpop\_bg}_i \times \text{IOUarea\_Wt}_i \times \text{CpolyA\_Wt}_{ij} \quad (5)$$

$$\text{totstr\_Cpoly}_{ij} = \text{totstr\_bg}_i \times \text{IOUarea\_Wt}_i \times \text{CpolyA\_Wt}_{ij} \quad (6)$$

where tothh , totpop and totstr pertain to the total number of households, people and residential structures, respectively, within a circuit polygon (Cpoly_{ij} , calculated) or CBG i (bg_i , from the 5-year estimates from the 2015 American

Community Survey⁵⁹), IOUarea_Wt_i is the portion of each block group's potentially inhabited area served by the IOU and CpolyA_Wt_{ij} is the portion of area served by circuit j . We did not multiply by the proportion of area that is potentially inhabited, thereby effectively reallocating the full reported block group population to potentially inhabited areas.

To check our approach, we compared our estimated number of households per circuit to the total residential customer base reported by each utility for each circuit. A perfect matching would give us a slope and R^2 of 1. Our slopes are 1 and 0.82, with R^2 values of 0.867 and 0.721 for PG&E and SCE, respectively (Supplementary Fig. 5). While we avoid drawing conclusions about specific circuits, we will discuss overall trends in grid limits for DER access aggregated across CBGs and each utility territory.

Hosting capacity is spatially allocated to households. After matching residential households to distribution circuits, we allocated hosting capacity available on those circuits to the households. The circuit polygons described in the previous section formed our units of analysis. Further allocation and data processing was performed in R (version 3.6.1)⁶⁰. Within each circuit polygon, the number of households, residential structures and people estimated by Equations (4)–(6) were assigned (1) the demographic characteristics of the associated block group i and (2) the characteristics of the electric infrastructure j serving them and its existing distributed generation and estimated DER hosting capacity. We used electric infrastructure data from the final PG&E and SCE ICA map updates in 2019^{57,61}.

PG&E and SCE report the existing, queued and total distributed generation on each circuit. The utilities' hosting capacity calculations consider the current state of the feeder and therefore factor in the existing distributed generation already interconnected to circuit lines⁵⁷. In estimating the number of households with access, we wanted to consider existing capacity alongside remaining hosting capacity. These values are provided at the full circuit level, and we allocated them to circuit polygons by the proportion of households we estimated to receive service there:

$$\text{DER\_exist}_{ij} \text{ (kW per household)} = \text{ExistDG}_j \text{ (kW)} \times \frac{\text{tothh\_Cpoly}_{ij}}{\text{tothh\_ctot}_j} \times \frac{1}{\text{tothh\_Cpoly}_{ij}} \quad (7)$$

where ExistDG_j is the existing distributed generation located on circuit j , tothh_ctot_j is the number of households served by circuit j , tothh_Cpoly_{ij} is the number of households located within the circuit polygon formed by CBG i and circuit j (from Eq. (4)), and DER_exist_{ij} is the existing distributed generation we estimate to be located in circuit polygon ij . For PG&E, we also scaled by the percentage of households served by portions of the circuit with ICA data, given that existing capacity can be located anywhere along the circuit, not just where ICA information exists. This method effectively estimates that each household located anywhere on a given circuit has access to the same amount of existing generation. (Other researchers have reported the locations of existing distributed generation (PV) by zip code and census tract⁶². However, we found that scaling our allocations of existing generation within a circuit by these values does not substantially impact our results.) The type of DER is not specified for existing generation. To remain conservative with respect to grid limits, we added the per-household value to each type of generation DER: PV, uniform generation, and their variants with operational flexibility limits.

In addition to existing distributed generation capacity connected to a particular circuit, ICA maps also report the remaining hosting capacity of load DERs and PV and uniform generation DERs (with and without operational flexibility constraints) that individual three-phase circuit segments can still accommodate. SCE provides ICA values for all of its three-phase circuit segments. As of December 2019, PG&E has reported ICA values for approximately 55% of all circuit segments (distributed throughout its territory); our results and discussion apply only to the segments with available data. (See Supplementary Note 6 for additional discussion of available ICA data and how they are used.) We compared service areas by demographic indicators to assess whether the portions of PG&E's territory with data are representative of the whole territory (Supplementary Fig. 6). We found no major differences (see the full discussion in Supplementary Note 7).

These hosting capacity values indicate how much additional DER capacity can be connected to that portion of the circuit without issue. However, adding DER capacity in one location may affect remaining hosting capacity elsewhere on the circuit; that is, the reported capacity allowances cannot be satisfied simultaneously. Moreover, hosting capacity values can vary widely within a given circuit due to constraints along different lines. According to SCE, 'the minimum values of all the feeders [represent] the value which can be connected anywhere [...] without exceeding the category limit'. In contrast, the maximum values can be accepted by some feeders 'based on location of interconnection'⁶³.

We allocated hosting capacity to circuit polygons using an approach designed to err towards less restrictive per-household grid limits while minimizing duplication. First, we selected the maximum values for each DER type reported for any circuit segment within a particular circuit polygon. We weighted these values

by the proportion of households served by that portion of the circuit (Eq. (8)) and normalized to preserve each circuit's total maximum hosting capacity (Eq. (9)):

$$\text{DER\_max\_hhWt}_{ij} \text{ (MW)} = \text{DER\_max\_Cpoly}_{ij} \text{ (MW)} \times \frac{\text{tothh\_Cpoly}_{ij}}{\text{tothh\_ctot}_j} \quad (8)$$

$$\text{DER\_max\_hhWt\_n}_{ij} \text{ (MW)} = \text{DER\_max\_hhWt}_{ij} \times \frac{\text{DER\_max\_ctot}_j}{\sum_j (\text{DER\_max\_hhWt}_{ij})} \quad (9)$$

where $\text{DER\_max\_Cpoly}_{ij}$ is the maximum hosting capacity (MW) reported within circuit polygon ij , which corresponds to the overlap between block group i and the estimated service area of circuit j , tothh_Cpoly_{ij} is the number of households within circuit polygon ij (from Eq. (4)), tothh_ctot_j is the total number of households estimated to be served by circuit j , DER_max_hhWt_{ij} is the household-weighted maximum hosting capacity (MW) for circuit polygon ij , DER_max_ctot_j is the maximum hosting capacity anywhere on circuit j and $\text{DER\_max\_hhWt\_n}_{ij}$ is the normalized household-weighted maximum hosting capacity for circuit polygon ij .

For a small minority of circuit polygons (0.05–1.60%, depending on DER type), the normalized hosting capacity value exceeds the maximum allowed hosting capacity in that circuit polygon. In these cases, we adjusted the value back to its allowed maximum:

$$\begin{aligned} \text{DER\_max\_hhWt\_nadj}_{ij} \text{ (MW)} \\ = \text{If } \text{DER\_max\_hhWt\_n}_{ij} > \text{DER\_max\_Cpoly}_{ij}, \\ \text{then } \text{DER\_max\_Cpoly}_{ij}, \text{ else } \text{DER\_max\_hhWt\_n}_{ij} \end{aligned} \quad (10)$$

where $\text{DER\_max\_hhWt\_nadj}_{ij}$ is the adjusted normalized hosting capacity value. Finally, we calculated the remaining per-household hosting capacity (DER_remain_{ij}) in kilowatts for each circuit polygon:

$$\text{DER\_remain}_{ij} \text{ (kW per household)} = \frac{\text{DER\_max\_hhWt\_nadj}_{ij} \text{ (MW)}}{\text{tothh\_Cpoly}_{ij}} \times 1,000 \quad (11)$$

Supplementary Table 4 contains these calculations for an example SCE circuit that spans eight CBGs and therefore creates eight circuit polygons. Supplementary Fig. 7 summarizes the resulting per-circuit hosting capacities for each utility.

Our final per-household hosting capacity (DER_{ij}) can then be estimated to be

$$\text{DER}_{ij} \text{ (kW per household)} = \text{DER\_exist}_{ij} + \text{DER\_remain}_{ij} \quad (12)$$

for each of the four generation DERs (where DER_exist_{ij} comes from Eq. (7)), and DER_remain_{ij} for the load DER. As there are some considerable outliers in the data, we capped all hosting capacity values to a maximum of 50 kW per household and a minimum of -10 kW per household for further analysis (negative values exist only for the load DER in SCE's territory).

Households need kilowatts of circuit capacity for DER access. We estimated the amount of circuit capacity needed to accommodate generation and load DERs, and, using the per-household hosting capacity values (Eq. (12)), assessed the ability of households to adopt these technologies given their local circuit limits. We focused our analysis on behind-the-meter PV deployment and potential new load due to EV charging, electrification and air-conditioning adoption.

In California, on average, a household consumes approximately 6.7 MWh of electricity annually⁶⁴, while a small building rooftop PV array produces approximately 1.48 MWh of electricity annually per kilowatt of installed capacity⁶⁵. A 4.5 kW PV system is therefore required, on average, to balance 100% of a household's annual electricity demand.

Researchers have previously defined access to behind-the-meter solar PV as the ability to install a 1.5 kW system. This threshold was chosen to be inclusive of existing adoption patterns: of the small (≤ 10 kW) PV systems installed prior to 2014, 96% were greater than 1.5 kW, and raising the threshold to 3 kW would exclude 19% of them⁶⁶. However, residential PV arrays have grown over time: the median system increased from 2.4 to 6.3 kW between 2000 and 2017 (Supplementary Fig. 8). Of the systems installed in 2017, 99% were over 3 kW and 94% were over 4 kW. The changing sizes of residential PV suggest that 1.5 kW may no longer be a reasonable threshold for future access, that is, if the economics show sufficient benefit at larger scales⁶², the ability to install only a small amount of solar may prevent someone from installing it at all.

We evaluated 'access' at 4.5 kW to estimate the ability of California households to offset their electricity consumption with onsite PV generation, and additionally for a range of thresholds (1.5 kW, for consistency with prior work, and then 2–10 kW by 1 kW increments) to track how this variable may influence limits to deployment. We assumed that every household would functionally have access to behind-the-meter PV if they had the ability to host 10 kW.

Yet access to behind-the-meter PV is not only limited by grid constraints. Other factors may also restrict the ability to adopt, including lack of suitable rooftop space, access to financing and home ownership. We considered economic and housing factors as demographic features, but combined building suitability limits with our estimates of grid constraints to calculate access to behind-the-meter PV based on technical limits. Researchers have estimated the percentage of small buildings (92.9–464.5 m²) within specific metropolitan areas and nationwide that are suitable to host 1.5 kW of PV on the basis of tilt, azimuth, shading and contiguous rooftop area⁹¹⁰. Small-building suitability percentages are available by zip code; we used census zip-code tabulation areas (ZCTAs)⁶⁶ to assign zip-code level values to block groups. (Some circuit polygons cross more than one ZCTA; for these, we averaged the values corresponding to all intersecting zip codes.)

We compared the restrictiveness of building characteristics to grid limits. We also proposed two approaches for combining building suitability and grid constraints to estimate the percentage of households unable to host solar due to either restriction. In the best case, we maximized double-counting of buildings deemed unsuitable due to either rooftop or grid limits by choosing the lower of the two percentages for a given circuit polygon. In the worst case, we maximized the number of households excluded by either criterion by adding the proportions of households without access.

Beyond solar PV, other DERs also require access to electric distribution circuits. For example, residential households with EVs typically rely on the ability to charge at home. EVs may use level 1 chargers, which require only a typical household outlet, or level 2 chargers, which enable much faster power delivery. While the power drawn by either type depends on the vehicle model, level 1 charging typically requires 1.4–1.9 kW. Level 2 charging can draw between 3.3 and 19.2 kW, with most vehicles requiring around 7 kW^{67,68}. Faster charging technologies can draw substantially more power, but they are less common at the household level, and we omitted them from consideration here.

Load electrification and air conditioning will also impact distribution circuits. California state policy has set targets for switching residential fossil fuel uses to electricity through the adoption of electric heat pumps for water and space heating. These technologies will create additional demand for electricity as these appliances become more widespread to support state policy to advance climate change mitigation and adaptation in California. Air conditioning, although already an electric appliance, will also increase load on the grid as additional households deploy new units to cope with increasing temperatures. In particular, low-income households are currently less likely to have air conditioning than high-income households⁶⁹.

We estimated the peak per-household electricity demand from electric water heating, space heating and air conditioning to be 0.6, 1.0 and 2.0 kW, respectively, using household energy consumption data from the 2009 California Residential Appliance Saturation Study⁶⁹ and hourly electricity consumption profiles from Energy and Environmental Economics⁷⁰. Details of the calculations are provided in Supplementary Note 8 and Supplementary Table 5.

For each DER type reported in the ICA data, we next calculated the percentage of households with access (hhwacc) within each circuit polygon for access thresholds of 1.5–10.0 kW per household:

$$\begin{aligned} \text{If } DER_{ij}(\text{kW per household}) > \text{threshold then } \text{hhwacc\_Cpoly}_{ij} &\leftarrow 100\% \\ \text{else} \\ \text{hhwacc\_Cpoly}_{ij} &\leftarrow DER_{ij}(\text{kW per household})/\text{threshold}(\text{kW per household}) \\ \text{end} \end{aligned} \quad (13)$$

where hhwacc_Cpoly_{ij} is the proportion of households located within circuit polygon *ij* that have access to the given DER type. Separately, we also calculated the proportion of households with greater than zero hosting capacity for each DER. We then aggregated our results up to the CBG and full utility territory levels by first summing over all circuit polygons *ij* within CBG *i*, then over all block groups:

$$\text{hhwacc\_bg}_i(\%) = \frac{\sum_j \text{hhwacc\_Cpoly}_{ij}(\%) \times \text{tothh\_Cpoly}_{ij}}{\sum_j \text{tothh\_Cpoly}_{ij}} \quad (14)$$

$$\text{hhwacc\_IOU}(\%) = \frac{\sum_i \text{hhwacc\_bg}_i(\%) \times \text{tothh\_bg}_i}{\sum_i \text{tothh\_bg}_i} \quad (15)$$

where hhwacc_bg_i is the proportion of households located within CBG *i* that have access to the given DER type, and hhwacc_IOU is the proportion of households located within that IOU's territory that have access to the given DER type. The block group-level results provide context for the distribution of access within a utility territory through meaningful units of contiguous geographic data within counties and census tracts. We relied heavily on boxplots to visualize the access results by block group. All boxplots in this work show the 25th, 50th and 75th percentiles of results, with whiskers extending to the furthest point within 1.5 times the interquartile range. Further points are shown as outliers.

Connecting household access results to demographic features. Hosting capacity values vary across IOU service territories, as do customer demographics and other indicators relevant to electric infrastructure and the customers it serves. We wanted to understand the relationship between these differences and hosting capacity (and, potentially, customers' ability to adopt DERs) among households for each DER type.

We constructed machine learning models to understand which features, if any, correlate most to per-household hosting capacity, and which are most important in building the models. We weighted our samples by tothh_Cpoly_{ij} to ensure the models appropriately emphasize circuit polygons that contain more households.

Linear and logistic regression models were used to determine whether linear relationships exist between our independent and dependent variables. When fitting, we normalized our independent variables to have a mean of zero and standard deviation of one. We used the regression coefficient and corresponding standard error of each feature to rank features in order of importance. We also calculated weighted root mean square errors (RMSEs) and R² values for the linear regression runs, and weighted score, precision and recall values for logistic regression.

Random forest regression and classification models were used to determine whether non-linear relationships exist in the data. We applied regression models to (1) all values of per-household hosting capacity and (2) the subset of hosting capacity values less than or equal to 10 kW per household (to specifically focus on the range where access may be limited). For each model, we used the lowest RMSE, as identified by tenfold cross-validation, to select the proportion of features considered at each split (all features, one-third of all features or the square root of all features), and used those results to calculate model outcomes and feature importances. We used the weighted RMSE (for regression) and the weighted score, precision and recall statistics (for classification) to evaluate model performance.

For each model, we used four combinations of infrastructure and demographic indicators as the independent variables: (1) all variables, (2) infrastructure variables only, (3) service and geographic variables, and (4) demographic variables. More information about each variable group is provided in Table 1, and a full list of variables is presented in Supplementary Tables 6–8.

Linear regression and random forest regression models used the per-household hosting capacity for each DER type as the dependent variable, while logistic regression and random forest classification models used a boolean value indicating whether the per-household hosting capacity surpasses a set threshold. We tested two thresholds: 1.5 and 10.0 kW per household.

We fitted and evaluated all models using the entire dataset rather than performing a train-test split. Our data correspond to the entire population in SCE's and PG&E's service territories (given available data); therefore, we were more interested in building models that represent the entire population than in predicting hosting capacity for unseen data.

Moving beyond machine learning models, we also evaluated the distribution of median hosting capacity across features. We focused in on the demographic features to evaluate how hosting capacity changes across feature values. We created bins for the available values of each demographic feature, then calculated the median per-household hosting capacity for each bin. LOESS curves were drawn on the plotted median values. These were weighted by the total number of households represented by each bin value and used span (smoothing) values calculated by generalized cross-validation. Confidence intervals were constructed using a bootstrap method with 1,000 replications, as described previously⁶, and we show the 50 and 90% confidence intervals for each LOESS curve.

Data availability

The definitions of features used in the demographic analyses are available in Supplementary Information Note 9 for convenience. Utility circuit data are available publicly from repositories that update approximately monthly and currently lack archive capability. The specific circuit data used in this study (from the last circuit map updates in 2019) are available at <https://github.com/Energy-MAC/GridLimitsforDERs>. Source data are provided with this paper.

Code availability

The code is available at <https://github.com/Energy-MAC/GridLimitsforDERs>.

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References

- Carley, S. & Konisky, D. M. The justice and equity implications of the clean energy transition. *Nat. Energy* **5**, 569–577 (2020).
- Johnson, O. W. et al. Intersectionality and energy transitions: a review of gender, social equity and low-carbon energy. *Energy Res. Soc. Sci.* **70**, 101774 (2020).
- Reames, T. G. Distributional disparities in residential rooftop solar potential and penetration in four cities in the United States. *Energy Res. Soc. Sci.* **69**, 101612 (2020).

4. Barbose, G., Forrester, S., Darghouth, N. & Hoen, B. *Income Trends among U.S. Residential Rooftop Solar Adopters. Technical Report* (Lawrence Berkeley National Laboratory, 2020).
5. Yu, J., Wang, Z., Majumdar, A. & Rajagopal, R. DeepSolar: a machine learning framework to efficiently construct a solar deployment database in the United States. *Joule* **2**, 2605–2617 (2018).
6. Sunter, D. A., Castellanos, S. & Kammen, D. M. Disparities in rooftop photovoltaics deployment in the United States by race and ethnicity. *Nat. Sustain.* **2**, 71–76 (2019).
7. Lukanov, B. R. & Krieger, E. M. Distributed solar and environmental justice: exploring the demographic and socio-economic trends of residential PV adoption in California. *Energy Policy* **134**, 110935 (2019).
8. Feldman, D., Brockway, A. M., Ulrich, E. & Margolis, R. *Shared Solar: Current Landscape, Market Potential, and the Impact of Federal Securities Regulation Report No. NREL/TP-6A20-63892* (National Renewable Energy Laboratory, 2015).
9. Margolis, R., Gagnon, P., Melius, J., Phillips, C. & Elmore, R. Using GIS-based methods and lidar data to estimate rooftop solar technical potential in US cities. *Environ. Res. Lett.* <https://doi.org/10.1088/1748-9326/aa7225> (2017).
10. Gagnon, P., Margolis, R., Melius, J., Phillips, C. & Elmore, R. Estimating rooftop solar technical potential across the US using a combination of GIS-based methods, lidar data, and statistical modeling. *Environ. Res. Lett.* <https://doi.org/10.1088/1748-9326/aaa554> (2018).
11. O'Shaughnessy, E., Barbose, G., Wiser, R., Forrester, S. & Darghouth, N. The impact of policies and business models on income equity in rooftop solar adoption. *Nat. Energy* **6**, 84–91 (2021).
12. Coddington, M. et al. *Updating Interconnection Screens for PV System Integration Report No. NREL/TP-5500-54063* (National Renewable Energy Laboratory, 2012); <https://doi.org/10.2172/1036038>
13. Smith, J., Rylander, M., Broderick, R. J. & Mather, B. *Alternatives to the 15% Rule: Modified Screens and Validation* (Electric Power Research Institute, 2015).
14. Cohen, M. A. & Callaway, D. S. Effects of distributed PV generation on California's distribution system, part 1: engineering simulations. *Sol. Energy* **128**, 126–138 (2016).
15. O'Shaughnessy, E., Barbose, G. & Wiser, R. Patience is a virtue: a data-driven analysis of rooftop solar PV permitting timelines in the United States. *Energy Policy* **144**, 111615 (2020).
16. McAllister, R., Manning, D., Bird, L., Coddington, M. & Volpi, C. *New Approaches to Distributed PV Interconnection: Implementation Considerations for Addressing Emerging Issues Report No. NREL/TP-6A20-72038* (National Renewable Energy Laboratory, 2019).
17. Bird, L. et al. *Review of Interconnection Practices and Costs in the Western States Report No. NREL/TP-6A20-71232* (National Renewable Energy Laboratory, 2018).
18. Barnes, C. *Comparing Utility Interconnection Timelines for Small-Scale Solar PV* (EQ Research, 2015).
19. *Decision Adopting Settlement Agreement Revising Distribution Level Interconnection Rules and Regulations – Electric Tariff Rule 21 and Granting Motions to Adopt the Utilities' Rule 21 Transition Plans* (California Public Utilities Commission, 2012).
20. Horowitz, K. A. W., Palmintier, B., Mather, B. & Denholm, P. Distribution system costs associated with the deployment of photovoltaic systems. *Renew. Sustain. Energy Rev.* **90**, 420–433 (2018).
21. Liu, Y., Bebic, J., Kroposki, B., de Bedout, J. & Ren, W. Distribution system voltage performance analysis for high-penetration photovoltaics. In *IEEE Energy 2030 Conference* (IEEE, 2008); <https://doi.org/10.1109/ENERGY.2008.4781069>
22. Widén, J., Wäckelgård, E., Paatero, J. V. & Lund, P. Impacts of distributed photovoltaics on network voltages: stochastic simulations of three Swedish low-voltage distribution grids. *Electr. Power Syst. Res.* **80**, 1562–1571 (2010).
23. Hoke, A., Butler, R., Hambrick, J. & Kroposki, B. Steady-state analysis of maximum photovoltaic penetration levels on typical distribution feeders. *IEEE Trans. Sustain. Energy* **4**, 350–357 (2013).
24. Navarro, A., Ochoa, L. F. & Randles, D. Monte Carlo-based assessment of PV impacts on real UK low voltage networks. *IEEE Power and Energy Society General Meeting 1–5* (IEEE, 2013); <https://doi.org/10.1109/PESMG.2013.6672620>
25. Nguyen, A. et al. High PV penetration impacts on five local distribution networks using high resolution solar resource assessment with sky imager and quasi-steady state distribution system simulations. *Sol. Energy* **132**, 221–235 (2016).
26. Wolske, K. S. More alike than different: profiles of high-income and low-income rooftop solar adopters in the United States. *Energy Res. Soc. Sci.* **63**, 101399 (2020).
27. Wang, Q., Kwan, M.-P., Fan, J. & Lin, J. Racial disparities in energy poverty in the United States. *Renew. Sustain. Energy Rev.* **137**, 110620 (2021).
28. Faust, J. et al. *CalEnviroScreen 3.0: Update to the California Communities Environmental Health Screening Tool. Technical Report* (California Environmental Protection Agency and Office of Environmental Health Hazard Assessment, 2017).
29. Canepa, K., Hardman, S. & Tal, G. An early look at plug-in electric vehicle adoption in disadvantaged communities in California. *Transp. Policy* **78**, 19–30 (2019).
30. Hsu, C.-W. & Fingerman, K. Public electric vehicle charger access disparities across race and income in California. *Transp. Policy* **100**, 59–67 (2021).
31. Hoke, A. & Komor, P. Maximizing the benefits of distributed photovoltaics. *Electr. J.* **25**, 55–67 (2012).
32. Walling, R. A., Saint, R., Dugan, R. C., Burke, J. & Kojovic, L. A. Summary of distributed resources impact on power delivery systems. *IEEE Trans. Power Deliv.* **23**, 1636–1644 (2008).
33. Katiraei, F. & Romero Agüero, J. Solar PV integration challenges. *IEEE Power Energy Mag.* **9**, 62–71 (2011).
34. Ismael, S. M., Abdel Aleem, S. H. E., Abdelaziz, A. Y. & Zobaa, A. F. State-of-the-art of hosting capacity in modern power systems with distributed generation. *Renew. Energy* **130**, 1002–1020 (2019).
35. Zain ul Abideen, M., Ellabban, O. & Al-Fagih, L. A review of the tools and methods for distribution networks' hosting capacity calculation. *Energies* **13**, 2758 (2020).
36. Mulenga, E., Bollen, M. H. J. & Etherden, N. A review of hosting capacity quantification methods for photovoltaics in low-voltage distribution grids. *Electr. Power Energy Syst.* **115**, 105445 (2020).
37. *Final Integration Capacity Analysis Working Group Report* (Integration Capacity Analysis Working Group, California Public Utilities Commission, 2017).
38. *Final Integration Capacity Analysis Working Group Long Term Refinements Report* (Integration Capacity Analysis Working Group, California Public Utilities Commission, 2018).
39. *Statistics and Charts* (2020) (California Solar Initiative Program Administrators, GRID Alternatives, California Investor Owned Utilities & California Public Utilities Commission, accessed 28 March 2020); <https://www.californiadgstats.ca.gov/charts/>
40. *California's Distributed Energy Resources Action Plan: Aligning Vision and Action* (California Public Utilities Commission, 2017).
41. *2019 Building Energy Efficiency Standards for Residential and Nonresidential Buildings* (California Energy Commission, 2018).
42. Borenstein, S. Private net benefits of residential solar PV: the role of electricity tariffs, tax incentives, and rebates. *J. Assoc. Environ. Resour. Econ.* <https://doi.org/10.1086/691978> (2017).
43. *2021 General Rate Case: Grid Modernization, Grid Technology, and Energy Storage* (Southern California Edison, California Public Utilities Commission, 2019).
44. *Order Instituting Rulemaking to Consider Streamlining Interconnection of Distributed Energy Resources and Improvements to Rule 21* (California Public Utilities Commission, 2017).
45. Brockway, A. M. & Delforge, P. Emissions reduction potential from electric heat pumps in California homes. *Electr. J.* **31**, 44–53 (2018).
46. *Joint Reply Comments of Southern California Edison Company (U 338-E), San Diego Gas & Electric Company (U 902-E), and Pacific Gas and Electric Company (U 39-E) on the Administrative Law Judge's Ruling Requesting Comments on Refinements to the Integration Capacity Analysis* (Southern California Edison, Pacific Gas and Electric, and San Diego Gas and Electric, California Public Utilities Commission, 2019).
47. Sergi, B. J. et al. Optimizing emissions reductions from the U.S. power sector for climate and health benefits. *Environ. Sci. Technol.* **54**, 7513–7523 (2020).
48. Krieger, E. M., Casey, J. A. & Shonkoff, S. B. C. A framework for siting and dispatch of emerging energy resources to realize environmental and health benefits: case study on peaker power plant displacement. *Energy Policy* **96**, 302–313 (2016).
49. Burillo, D. et al. *Climate Change in Los Angeles County: Grid Vulnerability to Extreme Heat. A Report for California's Fourth Climate Change Assessment Report No. CCCA4-CEC-2018-013* (California Energy Commission, 2018).
50. Esri. ArcGIS Desktop 10.6.1 quick start guide. (2017); <https://desktop.arcgis.com/en/arcmap/10.6/get-started/setup/arcgis-desktop-quick-start-guide.htm>
51. Patterson, W. Projection and Datum Guidelines. California Department of Fish and Wildlife (2018); <https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=109326&inline>
52. *2015 TIGER/Line Shapefiles* (United States Census Bureau, accessed 28 September 2018); <https://www.census.gov/geo/maps-data/data/tiger-line.html>
53. *California Protected Areas Database Version 2019b* (GreenInfo Network, accessed 14 January 2020); <https://data.cnra.ca.gov/dataset/california-protected-areas-database>
54. *California Conservation Easement Database Version 2019* (GreenInfo Network, accessed 14 January 2020); <https://data.cnra.ca.gov/dataset/california-conservation-easement-database>

55. *Military Installations, Ranges, and Training Areas* (2017) (United States Department of Defense, accessed 2 March 2019); <https://catalog.data.gov/dataset/military-installations-ranges-and-training-areas>
56. *California Electric Utility Service Areas* (California Energy Commission, 2015); https://www.energy.ca.gov/maps/serviceareas/electric_service_areas.html
57. *Integration Capacity Analysis (ICA) Map and User Guide* Version 1.4 (Pacific Gas and Electric, 2019); https://www.pge.com/en_US/for-our-business-partners/distribution-resource-planning/distribution-resource-planning-data-portal.page
58. *Distribution Resources Plan External Portal: Customer Type Breakdown* (2019) (Southern California Edison, accessed 18 September 2019); <https://ltmdrpep.sce.com/drpep/>
59. *2011–2015 ACS 5-Year Estimates* (2015) (United States Census Bureau, accessed 25 November 2018); <https://www.census.gov/programs-surveys/acs/technical-documentation/table-and-geography-changes/2015/5-year.html>
60. The R Project for Statistical Computing. R version 3.6.1. (2019); <https://cran.r-project.org/src/base/R-3/>
61. *Distribution Resources Plan External Portal and Interactive User Guide* (2019) (Southern California Edison, accessed 20 December 2019); <https://ltmdrpep.sce.com/drpep/>
62. Barbose, G. & Darghouth, N. *Tracking the Sun: Pricing and Design Trends for Distributed Photovoltaic Systems in the United States* (Lawrence Berkeley National Laboratory, 2019).
63. *Southern California Edison Company's (U 338-E) Demonstration Projects A and B Final Reports* (Southern California Edison, California Public Utilities Commission, 2016).
64. Rockzsfforde, R. R. *Comparative Analysis of Utility Services and Rates in California* (California Public Utilities Commission, 2015).
65. Gagnon, P. et al. *Rooftop Solar Photovoltaic Technical Potential in the United States: A Detailed Assessment* Report No. NREL/TP6A20-65298 (National Renewable Energy Laboratory, 2016).
66. *Zip Code Tabulation Areas* (2010) (United States Census Bureau, accessed 3 August 2020); <https://www.census.gov/programs-surveys/geography/guidance/geo-areas/zctas.html>
67. Szinai, J. K., Sheppard, C. J. R., Abhyankar, N. & Gopal, A. R. Reduced grid operating costs and renewable energy curtailment with electric vehicle charge management. *Energy Policy* **136**, 111051 (2020).
68. Hurlbut, D., McLaren, J., Koebrich, S., Williams, J. & Chen, E. *Electric Vehicle Charging Implications for Utility Ratemaking in Colorado. Background Research for the Colorado Public Utilities Commission* Report No. NREL/PR-6A20-73303 (National Renewable Energy Laboratory, 2019); <https://doi.org/10.2172/1503821>
69. Palmgren, C., Stevens, N., Goldberg, M., Barnes, R. & Rothkin, K. 2009 *California Residential Appliance Saturation Study* Report No. CEC-200-2010-004-ES (KEMA, California Energy Commission, 2010).
70. *Energy Efficiency Calculator: PG&E Residential Shape Viewer* Version 2.0 (Energy and Environmental Economics, 2017); https://www.ethree.com/public_proceedings/energy-efficiency-calculator/

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Author contributions

A.M.B., J.C. and D.C. conceptualized the research. A.M.B. and J.C. performed the research and wrote the paper. D.C. guided the research and edited the paper.

Competing interests

The authors declare the following competing interests: since completing the research described herein, J.C. has accepted employment at SCE. A.M.B. and D.C. have no competing interests.

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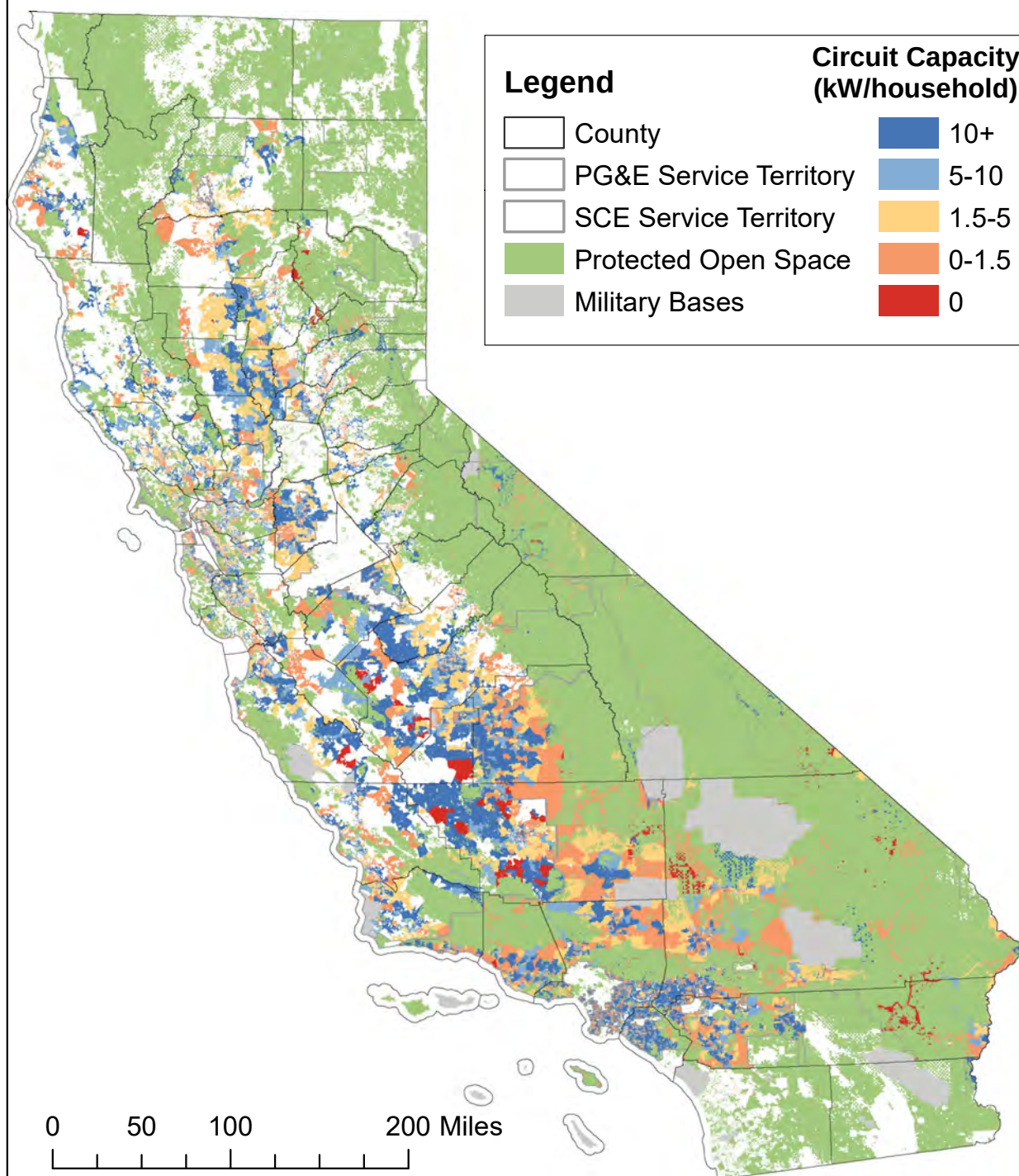
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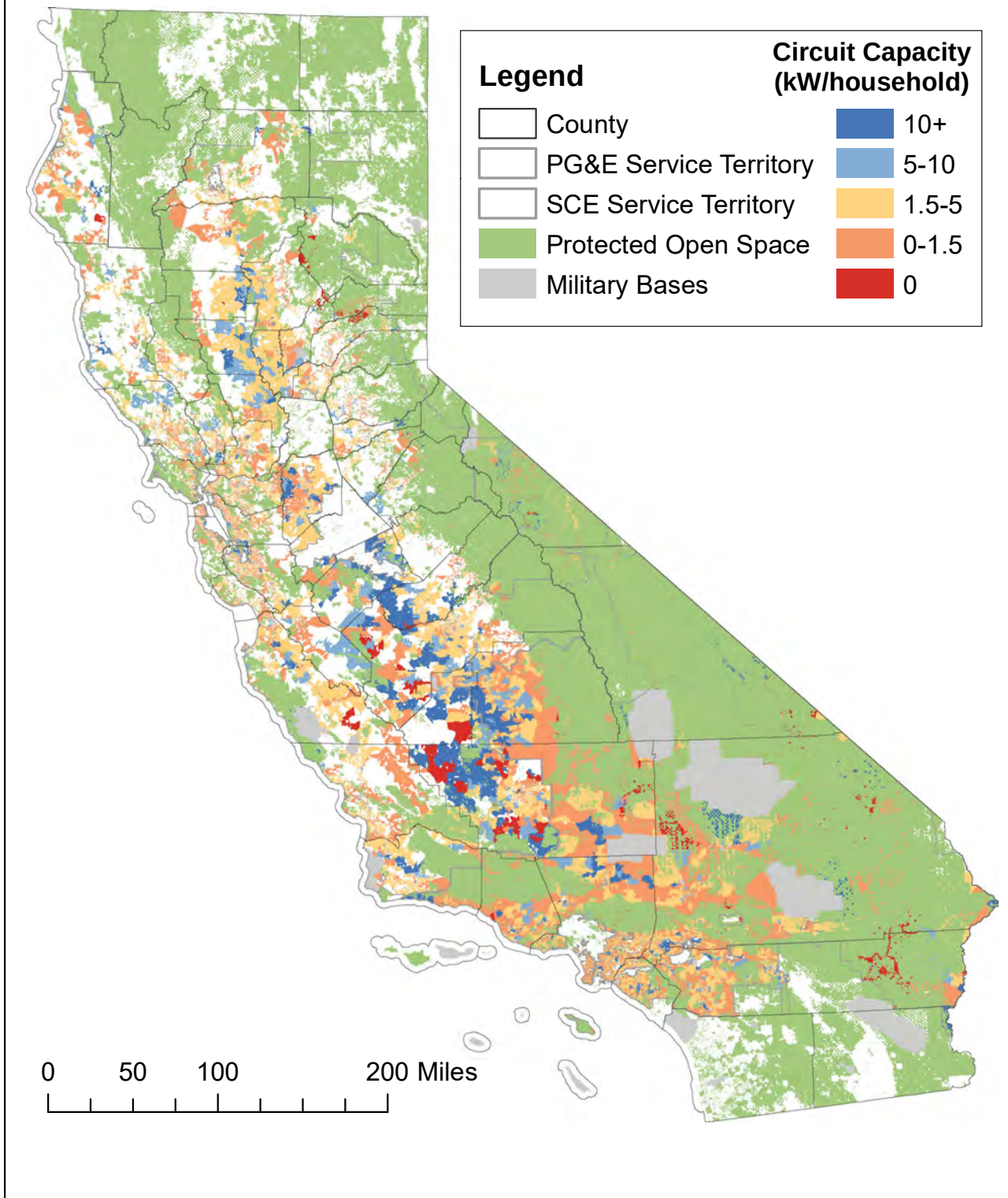
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Grid Limits for Distributed Energy Resources: PV



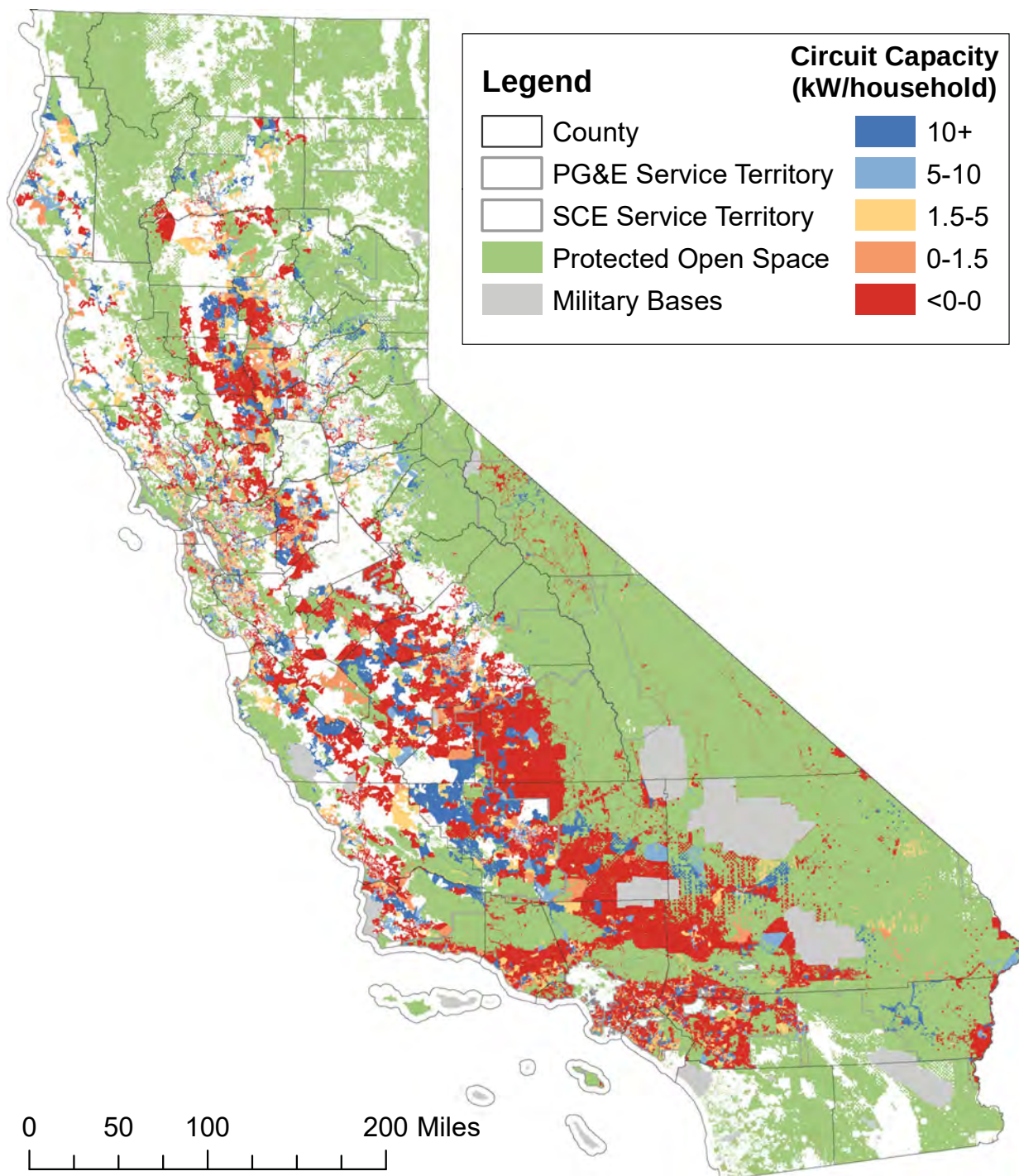
Extended Data Fig. 1 | Grid limits for distributed energy resources: PV. High-resolution version of Fig. 1a, showing hosting capacity limits for PV per household across PG&E and SCE service territories.

Grid Limits for Distributed Energy Resources: PV, with OpFlex Limits



Extended Data Fig. 2 | Grid limits for distributed energy resources: PV, with OpFlex limits. High-resolution version of Fig. 1b, showing hosting capacity limits for PV with Operational Flexibility limits enforced per household across PG&E and SCE service territories.

Grid Limits for Distributed Energy Resources: Load



Extended Data Fig. 3 | Grid limits for distributed energy resources: Load. High-resolution version of Fig. 1c, showing hosting capacity limits for Load per household across PG&E and SCE service territories.

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Energy decisions reframed as justice and ethical concerns

Benjamin K. Sovacool^{1,2*}, Raphael J. Heffron³, Darren McCauley⁴ and Andreas Goldthau^{5,6}

All too often, energy policy and technology discussions are limited to the domains of engineering and economics. Many energy consumers, and even analysts and policymakers, confront and frame energy and climate risks in a moral vacuum, rarely incorporating broader social justice concerns. Here, to remedy this gap, we investigate how concepts from justice and ethics can inform energy decision-making by reframing five energy problems — nuclear waste, involuntary resettlement, energy pollution, energy poverty and climate change — as pressing justice concerns. We conclude by proposing an energy justice framework centred on availability, affordability, due process, transparency and accountability, sustainability, equity and responsibility, which highlights the futurity, fairness and equity dimensions of energy production and use.

The structure of the global energy system and the pending consequences of climate change are among the central justice issues of our time, with profound implications for human happiness, welfare, freedom, equity and due process¹.

One global study distinguishing between ‘experienced’ and ‘imposed’ effects of climate change — essentially separating out primary emitters from those suffering from climate change — concluded that people in rich countries impose 200–300 times more health damage on others than they experience themselves as a result of their nation’s historical emissions². Others argue that the costs of climate change will befall the weakest and least developed countries as well as the poorest in developed nations, while the benefits, if there are any, will probably be accrued by the rich and powerful³.

Meanwhile, serious environmental burdens can arise from having too much energy (from waste, over-consumption and pollution⁴) or from not having enough (from lack of access to modern forms of energy, under-consumption and poverty). With increasing wealth, these environmental burdens shift in terms of severity, geographic scope and temporal reach. For instance, a decline in household environmental risks through enhanced access to modern energy services, clean water and better healthcare coincides with an increase in global risks such as climate change and other forms of transboundary environmental pollution. While solutions to some problems, such as poverty, obviously require an increase in energy consumption, solutions to other problems, such as climate change, might well require a decrease in energy consumption.

Clearly, the current fossil fuel-based global energy system has many benefits but also many disadvantages, including significant health burdens that shorten lives, undermine the conditions for happiness and impede a more just and equitable society. Yet most of us confront and frame such climate and energy risks within a moral vacuum. It has been argued that our moral systems are ill-equipped to handle the complexity and expansiveness of modern-day energy and climate problems^{5,6}, and that individuals will work to avoid feelings of responsibility for climate change or energy insecurity; some will even have optimistic biases, downgrading

any negative information they receive and counterbalancing it with almost irrational exuberance⁷.

In this Perspective, we argue that concepts from ethics and justice provide an important structure to think about, and approach, the world’s climate and energy dilemmas. We reframe five contemporary energy problems — nuclear waste, involuntary resettlement, energy pollution, energy poverty and climate change — as justice and ethics concerns. We then synthesize justice elements into a common framework that energy decision-makers can utilize to create a more just and equitable energy future. By ‘decision-makers’, we refer not only to the more traditional notion of policymakers and regulators, but also ordinary students, jurists, homeowners, businesspersons, investors and consumers — essentially, anyone that makes decisions or choices about energy conversion and use⁸. Admittedly, we take an anthropocentric perspective based on social justice principles, though there are certainly justice claims that arise with how humans interact with non-human forms of life. Some have called this human-centered approach ‘cosmopolitan justice’, as it acknowledges that all ethnic groups belong to a single community based on a collective morality⁹. Many scholars have taken up modern manifestations of these ideals, and have advanced the core arguments presented in Table 1^{10–19}. These arguments underscore how all human beings have equal moral worth and, as we will argue, are deserving of ‘energy justice’.

Reframing five energy problems as justice concerns

The five modern energy problems considered here cover what has been called the ‘wholesale’ and ‘retail’ attributes of justice: whether institutions are fair and impartial (in the case of involuntary resettlement and energy poverty); and whether individual outcomes are equitable (in the case of pollution, nuclear waste and climate change)²⁰.

These examples are not meant to be exhaustive and cover only a narrow range of the full spectrum of possible theories and energy systems. Nor do they represent any definitive stance on which justice principles are absolutely agreed within the community of

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Table 1 | Core elements of cosmopolitan justice.

An argument for:	Explanation
Individualism	Human beings and persons are the ultimate concern, not communities or nation states
Universality	Justice concerns apply to everyone equally, regardless of their gender or social status
Responsibility	The way to individual and communal mutual benefit is to treat others as they themselves would wish to be treated
Identity	Although we are influenced by cultures and diverse perspectives, one is a member of a global community of human beings

theorists or practitioners — healthy debates over the universality or relevance of justice principles continue to this day^{21,22}. Instead, the justice theories utilized here were selected based on those being established within the field that are well known to the authors, and those easily applied to the energy sector. Although in many situations the justice principles elaborated below could apply across many energy issues, we have limited the discussion to one principle per problem to retain focus and depth.

Involuntary resettlement as a violation of procedural justice. Millions of individuals are involuntarily resettled due to energy projects every year in ways that violate modern notions of due process or procedural justice: planners are imposing on the free choice of individuals. Annually, about 4 million people are displaced by activities relating to hydroelectricity construction or operation, with 80 million displaced in the second half of the last century by the construction of 300 large dams²³. The Dene, Cree and Metis indigenous peoples — inhabitants of North America for 12,000 years — have been repeatedly resettled by the expansion of oil tar sands production in Alberta, Canada²⁴. One wide-ranging international survey estimated that between 1950 and 2009 at least 2.6 million people were displaced due to mining in India, while individual mines in Brazil, Ghana, Indonesia and South Africa have each involuntarily displaced between 15,000 and 37,000 people from their homes²⁵. In many instances, this happens without consent, without advance notification and without an opportunity to seek redress for damages²⁶.

Such practices can be framed as violations of procedural justice, which emphasizes principles of due process, representative justice and justice as public participation²⁷. Generally, these ideas centre on the following interrelated justice issues: who gets to decide and set rules and laws, and which parties and interests are recognized in decision-making? By what process do they make such decisions? And how impartial or fair are the institutions, instruments and objectives involved? Procedural theories of justice are all concerned with process — with the fairness and transparency of decisions, the adequacy of legal protections, and the legitimacy and inclusivity of institutions involved in decision-making²⁸. Put another way, procedural justice deals with recognition (who is recognized), participation (who gets to participate) and power (how is power distributed in decision-making forums)²⁹. It pushes for concepts similar to those in environmental and risk policy, discussions known as the ‘deliberative turn’ towards democracy and engagement³⁰.

Procedural justice seeks to ensure that the potential for stakeholder participation in the energy policymaking process at least roughly matches the importance (in aggregate and to each person affected) of the matter at stake and the irrevocability of any decisions that may be reached. It also necessitates effective recourse through judicial and administrative remedies and forms of redress. It suggests that communities must be involved in deciding about projects that will affect them; environmental and social impact assessments must involve genuine community consultation; and neutral arbitration should be available to handle grievances. It can, through free, prior, informed consent, demand proper representation of communities (including marginalized groups) and true power-sharing^{31,32}, and it has facilitated further protections over the past few decades

known as impact–benefit agreements³³, social licences to extract³⁴ and social licences to operate³⁵.

Fossil fuel pollution as a human rights concern. Power plants and conventional automobiles release a variety of noxious pollutants into the air that threaten human health and the vitality of crops, fisheries, forests and natural habitats. However, these are unevenly distributed and produce inequitable impacts on children and minorities. Children, in particular, are vulnerable to the pollution from fossil fuels — they spend more time outdoors, breathe 50% more air per unit of body weight than adults, ingest polluted air while their respiratory systems are still developing and are less likely to recognize symptoms, leading to delays in treatment³⁶.

Meanwhile, in the US, for instance, people of colour and minorities bear a disproportionate share of poisons and environmental hazards³⁷. The proximity of energy infrastructures to indigenous communities, such as Native Americans, has resulted in serious health inequalities³⁸. One meta-analysis of environmental pollution across 2,083 counties in the US found that toxic releases increase as a function of the number of minorities in the local population³⁹. African Americans receive emergency hospital treatment for asthma attacks more than four times the national average, and have children three times as likely to be hospitalized for treatment of asthma⁴⁰.

In eastern Europe, the Roma have been displaced from so many countries and cities that they are forced to reside in settlements akin to ‘environmental time bombs’. Roma communities in the Czech Republic and Slovakia, for example, reside in flats located above abandoned mines, where they are vulnerable to flooding and susceptible to breathing methane gas. Others live in abandoned factory sites surrounded by mining wastes where children are fully exposed to toxins and suffer long-term health effects⁴¹. The Roma living along the Upper Tisza River in Hungary also must confront the highest risks of floods in the entire country⁴². Other studies of energy facilities have confirmed that the poor or marginalized suffer a ‘triple jeopardy’ of being most exposed to higher levels of pollution, more vulnerable and likely to suffer health impacts, and least responsible for generating environmental problems in the first place²⁷.

Such pollution can be reframed not only as a health concern, but also one of justice and human rights. Theories of justice centred on human rights hold that certain interests of individual persons are more important than the interests of society; that is, a just society always respects and dignifies the individual^{43,44}. Rights-centred notions of justice have a long history enshrined in all major religions and dating all the way back to antiquity (and probably further), whereas modern notions cut across the categories of civil, cultural, economic, political and social rights. These modern iterations extend to basic issues of bodily health and integrity, freedom from fear and the right to enjoy an uncontaminated environment capable of sustaining established patterns of life.

Energy poverty as a violation of distributive justice. Almost 4 billion people remain mired in ‘energy poverty’, a term that connotes a lack of access to modern energy services, especially the provision of electricity or cleaner forms of cooking. This number includes approximately 1 billion people (15% of the global population, one in seven people) still lacking access to electricity and approximately

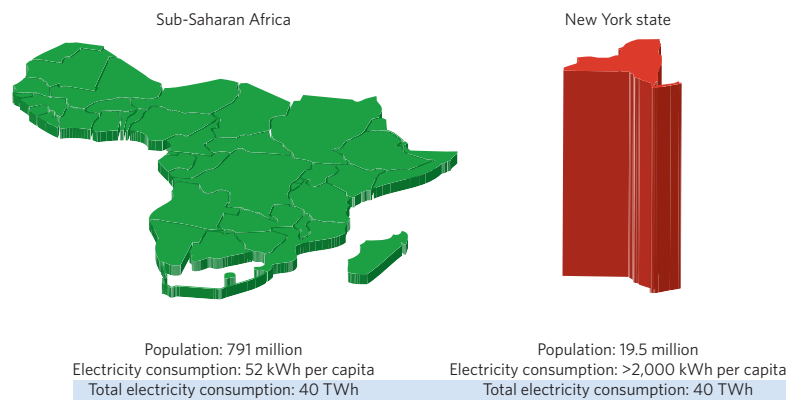


Figure 1 | Disparities in electricity consumption between New York state and sub-Saharan Africa. Strikingly, the state of New York in the US, home to less than 20 million residents, consumes in aggregate approximately the same amount of electricity each year as the 791 million people of sub-Saharan Africa (excluding South Africa). New York residents consume more than 2,000 kWh per capita annually compared with sub-Saharan Africans, who each consume about 52 kWh. Data taken from ref. 84. Africa map, © YAY Media AS / Alamy Stock Vector; New York state map, © Rainer Lesniewski / Alamy Stock Vector.

2.9 billion people (more than two in five) dependent on traditional forms of cooking (that is, cooking based on solid fuels such as dung or burning biomass), which are highly polluting⁴⁵. As Fig. 1 indicates, although the state of New York, USA, may produce more net gross domestic product, its residents consume the same amount of electricity as the 791 million people of sub-Saharan Africa and western Africa, a per capita consumption ratio 38 times higher.

People with limited or no access to energy services will generally have fewer educational opportunities, less access to fertile land and other natural resources, poorer health, negligible political representation, limited economic opportunities and inadequate access to health services⁴⁶. The health impacts of energy poverty are particularly acute, with one recent study finding that emissions from residential energy use (such as heating and cooking) have the largest impact on premature mortality globally⁴⁷. That study estimated 3.3 million premature deaths in 2010 — an amount greater than those perishing from malaria and tuberculosis — and predicts as many as 6.5 million premature deaths by 2050 (12.5 deaths per minute), which would be far greater than the number suffering from HIV/AIDS. For those with access to energy, the poor are also disproportionately affected by oil price volatility. As a United Nations (UN) Development Programme study estimates, the oil price fluctuations between 2002 and 2005 made low-income households in developing Asia spend 171% more of their income on cooking fuels, 67% more on electricity and 55% more on lighting, often making people revert to tradition forms of energy⁴⁸.

This unequal distribution of modern energy services can be framed as violating notions of distributive justice, whose theories are concerned with how social goods and ills are allocated among society^{49,50}. Distributive justice deals with three aspects: what goods, such as wealth, power, respect, food or clothing, are to be distributed? Between what entities are they to be distributed (for example, living or future generations, members of a political community or all humankind)? And what is the proper mode of distribution — is it based on need, merit, utility, entitlement, property rights or something else?

Distributive justice theorists argue that, if physical security is a basic right, then so are the conditions that create it, such as employment, food, shelter and a healthy living environment⁵¹. People are, therefore, entitled to a certain set of minimal energy services or 'subsistence rights' that enable them to enjoy a basic minimum of wellbeing; included in this set of goods is the right to modern energy services^{52–54}. People have a 'positive right' to a clean and safe

environment and to levels of energy services that provide them with a happy and healthy life⁵⁵.

Nuclear waste as an insult to future generations. Whatever one's stance on nuclear power may be, one of its least controversial aspects is that it produces long-lived waste. A single nuclear reactor will typically consume an average of 32,000 fuel rods over the course of its lifetime, and it will also produce 20–30 tonnes of spent nuclear fuel per year — an average of about 2,200 tonnes annually for the entire US nuclear industry⁵⁶. The global nuclear industry creates almost five times that amount each year — 10,000 tonnes of high-level spent nuclear fuel — and the 31 countries operating nuclear power plants reported a total of 270,000 tonnes of accumulated spent fuel worldwide in 2015⁵⁷. About 85% of this waste is not reprocessed and most of it is stored onsite in special facilities at nuclear power plants⁵⁸.

Nuclear power fosters an unbreakable commitment whereby society benefits from electricity generation for a few decades, but in return has to bear the costs of managing nuclear waste for astonishingly long periods, often measured in millennia; one physicist even termed this a Faustian bargain⁵⁹. Put in terms perhaps easier to comprehend, nuclear reactors produce waste that will persist for longer than human civilization has practised Catholicism, longer than humans have cultivated crops and longer than our species has existed, provoking some to classify such energy infrastructure as essentially 'immortal'⁶⁰.

If one believes that there is a moral responsibility of current generations to protect future ones^{61,62} — whereby people in the future have a right to enjoy a good life just as we do, but one undisturbed by damage or waste that our energy systems will inflict over time^{63,64} — then this waste is an imposition and burden^{65,66}. Nuclear waste, in particular, can be reframed as a pernicious problem for future generations for at least three other reasons. First, it introduces a cost problem: even if the waste does not leak, and technical standards ensure it is safe and protection remains at present levels, the costs of maintaining that waste are unfair, as only the present generation receives the benefits of nuclear electricity, yet they do not have to bear the full financial burden of the waste. In other words, nuclear waste is a classic case of socializing costs to future taxpayers while privatizing immediate benefits to the nuclear industry and present consumers⁶⁷. Second, managing nuclear waste introduces a problem of capability, as it potentially erodes the ability of future generations to retain present levels of technological and managerial capacity that

might be lost somehow, due to social or even armed conflicts over nuclear waste sites⁶⁸. Third, it introduces the problem of mistakes, a situation where future generations face the risk of some type of accident, earthquake, or natural disaster that results in a catastrophic release of radiation⁶⁹.

Climate change as contravened responsibility. Historically, the US and western Europe account for about two-thirds of the primary build-up of carbon in the atmosphere, whereas the entire continent of Africa is responsible for just 3% of global emissions⁷⁰. However, depending on the methodology utilized, 75–80% of the costs of climate change will be borne by those in developing countries^{71,72}, varying according to their national economic structures, geographies and resilience⁷³. Indeed, looking at patterns of fatalities and economic damages from natural disasters, developing countries suffered 91% of fatalities and 51% of financial losses but accounted for only 12% of insured losses in 2007⁷⁴. Over the period from 1970 to 2008, the Intergovernmental Panel on Climate Change estimated that 95% of natural disaster-related deaths occurred in developing countries⁷⁵.

Through this lens, responding to climate change by building resilience — pursuing adaptation — is a global effort whose responsibility should befall mostly historical emitters, yet determining responsibility is a critical element for consideration⁷⁶. From the justice and ethics perspective, the activities of one group of persons and countries overusing the atmosphere as their carbon ‘dump’ have caused, and continued to cause, injury to a different, much larger group. This is a matter of ‘corrective’ justice, as one group has engaged in wrongfully injuring another group, meaning the guilty should desist from their harmful actions and compensate their victims for damages⁷⁷. Polluters and industrializing countries, the thinking goes, should be required to ‘clean up their own mess’ and support others in adaptation. Part of the argument is historical, as industrializing countries have emitted the most carbon into the atmosphere to reach current levels. Another part is an argument from ecology, as one could characterize the atmosphere as a sink with limited space. Rich countries have exhausted the capacity of this sink, denied other countries their shares, and are required to pay compensation for this overuse⁷⁸. Such inequalities must be reversed by imposing extra burdens on the countries and peoples responsible for inflicting and producing those inequalities^{55,79}. Adaptation offers us the ability to subsume this responsibility⁸⁰. There is a responsibility of governments to minimize environmental degradation and of industrialized countries responsible for climate change to pay to fix the problem (the so-called polluter pays principle)^{77,79}.

Towards an energy justice framework

As is perhaps obvious to readers by now, not all of the five justice frames presented above align with each other. To illustrate this point, consider a situation in which a community needs to make decisions on depletion rates of a given natural resource. The future generations criterion would suggest to set slow depletion rates, which would also fall in line with the principle that future generations should not be impacted by damage caused by the present energy systems. Yet, an important aspect of distributive justice also pertains to maximizing the utilization of resources to facilitate access by the poor and vulnerable. The latter, however, demands that we substantively increase access to energy systems and thus consumption. Some justice criteria call for expanded depletion, others for restricted depletion.

With this in mind, and in attempting to synthesize these divergent strands of thought, we define energy justice as a global energy system that fairly disseminates both the benefits and costs of energy services, and one that contributes to more representative and impartial energy decision-making. It involves the following key elements:

- Distribution of costs, or how the hazards and externalities of the energy system are disseminated throughout society;
- Distribution of benefits, or how access to modern energy systems and services is distributed throughout society;
- Procedures, or ensuring that energy decision-making respects due process and representation.

These three components bring together core understandings of distributional and procedural justice alongside cosmopolitan (albeit anthropocentric) interpretations of equity and fairness. This conceptualization of energy justice demands that we seriously consider whether it is fair that one-quarter of humanity has no access to cleaner forms of cooking or electricity, and another quarter has less than one-tenth of what those in industrializing countries had a decade ago. It challenges us not only to coldly calculate costs and benefits, but to determine how these are distributed. It asks that we decide whether it is fair to deplete hundreds of millions of years of energy resources in a few generations, or to reap the benefits corresponding to greenhouse gas emissions, such as economic development, today at the expense of those not yet born tomorrow. It demands that we provide meaningful involvement and access to the decision-making process. It ensures the availability of information about energy, a condition of participation and informed consent. It subscribes to the notion of participatory governance as a mechanism of fostering comprehensive stakeholder inclusion and transparency as it seeks to represent minorities in decision-making, at all stages of the energy process, from agenda setting and formulation to siting and evaluation. It requires us to provide access to legal processes for challenging violations of human rights. Our conceptualization denies any such limits to where energy justice ought to apply, such as community boundaries to the scope of responsibilities, which instead hold regardless of space and time, apply across cultures and apply ahead to future generations.

To operationalize the somewhat lofty moral elements of energy justice intimated above, Table 2 presents an energy justice framework based on eight principles that can be applied readily to real-world problems. We hope that this concept of energy justice can provide a common philosophical grounding to energy researchers and the energy community that can unite how we get to our targeted energy goals, whether they be for 2030, 2050 or beyond. It is a mechanism that can begin to achieve a more just and equitable balance of all the competing aims in energy policy and ensure that the trade-offs that are made in the energy sector are inherently more just and equitable in their societal outcomes, rather than favouring different sections or factions in society.

Discussion

The concepts and tools offered by philosophy and justice theory are complex and diverse; some overlap with others and each has their own particular themes and leading advocates. Despite this variation, however, such concepts suggest multiple conclusions for energy and climate research and practice.

First, we need to think about energy technology and systems as more than simply hardware, as beyond a black box. They are not merely devices for distributing barrels of oil, conduits for cubic metres of natural gas, mechanisms for conveying coal, or intricate sociotechnical systems delivering electricity, mobility, heat and so forth. Instead, energy systems can also be mechanisms of resource extraction that deplete assets available for future generations for the benefit of present ones, systems of segregation that separate negative externalities of energy production from the positive attributes of energy consumption, and symbols of exclusion, marginalization, or unfair decision-making processes. To some, energy systems and their effects on the climate and society can even impinge on notions of spirituality and religion^{81,82}. Assessments of energy

Table 2 | Energy justice decision-making framework.

Principle	Description	Contemporary applications
Availability	People deserve sufficient energy resources of high quality	Investments in energy supply and energy efficiency; upgrades to infrastructure
Affordability	The provision of energy services should not become a financial burden for consumers, especially the poor	Fuel poverty eradication efforts; low-income assistance for weatherization efficiency improvements; retrofits to older buildings
Due process	Countries should respect due process and human rights in their production and use of energy	Social and environmental impact assessments; free, prior and informed consent
Transparency and accountability	All people should have access to high-quality information about energy and the environment, and fair, transparent and accountable forms of energy decision-making	The Extractive Industries Transparency Initiative; independent accountability mechanisms; international accounting standards for energy subsidies
Sustainability	Energy resources should not be depleted too quickly	Natural resource funds designed to save for future generations; system benefits charges
Intragenerational equity	All people have a right to fairly access energy services	The UN's Sustainable Energy for All initiative; Sustainable Development Goal 7
Intergenerational equity	Future generations have a right to enjoy a good life undisturbed by the damage that our energy systems inflict on the world today	Promoting environmentally friendly forms of low-carbon energy such as renewables or efficiency that can minimize externalities or prolong resource efficacy; implementing environmental bonds
Responsibility	All nations have a responsibility to protect the natural environment and reduce energy-related environmental threats	UN Framework Convention on Climate Change; the Green Climate Fund

systems that ignore these (sometimes hidden) dimensions threaten to make them appear natural or normal. In extreme cases, injustices can become crystallized into energy infrastructure by project planners, or accumulate through years of routines and practices by consumers.

Second, energy analysis and planning should be informed by more than the usual tools of cost–benefit analyses, techno-economic models, or scientific and engineering projections about new technologies or scenarios. Energy system interventions are about more than technology and economic development; they are about political power, social cohesion, and even ethical and moral concerns over equity, due process and justice. Energy systems can be reconceived as a political, deliberative challenge involving the satisfaction of competing preferences; a social dilemma pitting, at times, the climatic and development goals of energy security or improved resilience against the pressing needs of marginalized and vulnerable populations; and a moral quandary revolving around how energy burdens and benefits are fairly, or unfairly, disseminated. No matter how noble the intentions of engineers and planners, or how well interventions or new energy systems are designed, they have their own inescapable underlying ramifications for justice. Perhaps more personally, even readers convinced that they may be ‘winners’ of the existing energy system today could find themselves — or their future kin — ‘losers’ tomorrow.

As such, we hold that energy issues can be reframed not only as matters of national security, economic competitiveness or environmental degradation, but as matters of social justice. Many justice theorists would question the underlying morality of forcing people to abandon their homes for energy projects, imposing the burden of pollution on the young and vulnerable, violating basic civil liberties and human rights, misappropriating energy funds and creating an energy system with unequal access. This demands that contemporary analysts, policymakers and even consumers should begin to reconsider their energy decisions as not only technical, economic or even environmental concerns, but also as moral ones.

In sum, a conceptual account of justice, even if well-grounded in philosophical theory, is of little consequence unless it can actually inform and influence energy practices, decision-makers and public choices. Or, to paraphrase from the justice literature, with ethics the proof in the pudding lies not in its making, but in its eating⁸³.

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References

- Jones, B. R., Sovacool, B. & Sidortsov, R. V. Making the ethical and philosophical case for ‘energy justice’. *Environ. Ethics* **37**, 145–168 (2015).
- Smith, K. R., Desai, M. A., Rogers, J. V. & Houghton, R. A. Joint CO₂ and CH₄ accountability for global warming. *Proc. Natl Acad. Sci. USA* **110**, E2865–E2874 (2013).
- Matthew, R. A. in *Climate Change: What it Means for Us, Our Children, and Our Grandchildren* (eds DiMento, J. F. C. & Doughman, P.) 161–180 (MIT Press, 2007).
- Wilkinson, P., Smith, K., Joffe, M. & Haines, A. A global perspective on energy: health effects and injustices. *Lancet* **370**, 965–977 (2007).
- Jamieson, D. *Reason in a Dark Time: Why the Struggle Against Climate Change Failed — and What it Means for Our Future* (Oxford Univ. Press, 2014).
- Markowitz, E. M. & Shariff, A. F. Climate change and moral judgment. *Nature Clim. Change* **2**, 243–247 (2012).
- Stoknes, P. E. Rethinking climate communications and the psychological climate paradox. *Energy Res. Soc. Sci.* **1**, 161–170 (2014).
- Sovacool, B. K. & Dworkin, M. *Global Energy Justice: Problems, Principles, and Practices* (Cambridge Univ. Press, 2014).
- Moellendorf, D. *Cosmopolitan Justice* (Westview, 2002).
- Beitz, C. Cosmopolitan ideals and national sentiment. *J. Philos.* **80**, 591–600 (1983).
- Held, D. *Cosmopolitanism: Ideas and Realities* (Polity, 2010).
- Pogge, T. Cosmopolitanism and sovereignty. *Ethics* **103**, 48–75 (1992).
- Sen, A. *Resources, Values and Development* (Harvard Univ. Press, 1984).
- Sen, A. *Development as Freedom* (Oxford Univ. Press, 1999).
- Nussbaum, M. C. *Creating Capabilities: the Human Development Approach* (Belknap, 2011).
- Singer, P. *One World: the Ethics of Globalization* (Yale Univ. Press, 2002).
- Brock, G. *Global Justice: a Cosmopolitan Account* (Oxford Univ. Press, 2009).
- Weiss, E. B. In *Fairness to Future Generations: International Law, Common Patrimony, and Intergenerational Equity* (Transnational, 1989).
- Harris, P. G. in *Ethics and Global Environmental Policy: Cosmopolitan Conceptions of Climate Change* (ed. Harris, P. G.) 1–19 (Edward Elgar, 2011).
- Barry, B. *Theories of Justice* (Univ. California Press, 1989).
- Hinman, L. M. *Ethics: a Pluralistic Approach to Moral Theory* (Wadsworth, 2008).
- Sandel, M. *Justice: What's the Right Thing to Do?* (Farrar, Straus and Giroux, 2009).
- World Commission on Dams *The Report of the World Commission on Dams* (Earthscan, 2001).
- Walsh, S. & Stainsby, M. in *Sparking a Worldwide Energy Revolution: Social Struggles in the Transition to a Post-Petrol World* (ed. Abramsky, K.) 341–352 (AK, 2010).

25. Downing, T. E. *Avoiding New Poverty: Mining-Induced Displacement and Resettlement* (International Institute for Environment and Development, 2002).
26. Hunter, D. Using the World Bank Inspection Panel to defend the interests of project-affected people. *Chic. J. Int. Law* **4**, 201–211 (2003).
27. Walker, G. *Environmental Justice: Concepts, Evidence, and Politics* (Routledge, 2012).
28. Weston, B. H. Climate change and intergenerational justice: foundational reflections. *Vermont J. Environ. Law* **9**, 375–430 (2008).
29. Paavola, J., Adger, W. N. & Huq, S. in *Fairness in Adaptation to Climate Change* (eds Adger, W. N. et al.) 263–277 (MIT Press, 2006).
30. Habermas, J. *Between Facts and Norms: Contributions to a Discourse Theory of Law and Democracy* (MIT Press, 1996).
31. Colchester, M. & Ferrari, M. F. *Making FPIC - Free, Prior and Informed Consent - Work: Challenges and Prospects for Indigenous People* (Forest Peoples Project, 2007).
32. United Nations *Free Prior Informed Consent and Beyond: the Experience of IFAD* (IFAD, 2005).
33. Hitch, M. & Fidler, C. R. Impact and benefit agreements: a contentious issue for environmental and aboriginal justice. *Environments J.* **35**, 45–69 (2007).
34. Tilton, J. E. Mineral endowment, public policy and competitiveness: a survey of issues. *Resour. Policy* **18**, 237–249 (1992).
35. Wilburn, K. M. & Wilburn, R. Achieving social license to operate using stakeholder theory. *J. Int. Bus. Ethics* **4**, 3–16 (2011).
36. Kleinman, M. T. *The Health Effects of Air Pollution on Children* (Univ. California Press, 2000).
37. Ard, K. Trends in exposure to industrial air toxins for different racial and socioeconomic groups: a spatial and temporal examination of environmental inequality in the U. S. from 1995 to 2004. *Soc. Sci. Res.* **53**, 375–390 (2015).
38. Holifield, R. Environmental justice as recognition and participation in risk assessment: negotiating and translating health risk at a superfund site in Indian country. *Ann. Assoc. Am. Geogr.* **102**, 591–613 (2012).
39. Allen, D. W. Social class, race, and toxic releases in American counties. *Soc. Sci. J.* **38**, 13–25 (2001).
40. Ottaviano, D. M. *Environmental Justice: New Clean Air Act Regulations and the Anticipated Impact on Minority Communities* (Lawyer's Committee for Civil Rights Under Law, 2003).
41. Steger, T. *Making the Case for Environmental Justice in Central and Eastern Europe* (CEU Center for Environmental Law and Policy, 2007).
42. Linnerooth-Bayer, J. & Vari, A. in *Fairness in Adaptation to Climate Change* (eds Adger, W. N. et al.) 239–259 (MIT Press, 2006).
43. Berkovitz, D. M. Pariahs and prophets: nuclear energy, global warming, and intergenerational justice. *Columbia J. Environ. Law* **17**, 245–326 (1992).
44. Dworkin, R. M. *Taking Rights Seriously* (Harvard Univ. Press, 1978).
45. *Global Tracking Framework: Energy Access* (World Bank, 2015).
46. Sovacool, B. K., Sidortsov, R. V. & Jones, B. R. *Energy Security, Equality, and Justice* (Routledge, 2014).
47. Lelieveld, J., Evans, J. S., Giannadaki, D., Fnais, M. & Pozzer, A. The contribution of outdoor air pollution sources to premature mortality on a global scale. *Nature* **525**, 367–371 (2015).
48. *Overcoming Vulnerability to Rising Oil Prices: Options for Asia and the Pacific* (UNDP, 2007).
49. Rawls, J. A *Theory of Justice* Revised edn (Belknap, 1999).
50. Dworkin, R. M. *Sovereign Virtue: the Theory and Practice of Equality* (Harvard Univ. Press, 2000).
51. Shue, H. in *The Ethics of Global Climate Change* (ed. Arnold, D. G.) 292–314 (Cambridge Univ. Press, 2011).
52. Rao, N. & Baer, P. “Decent living” emissions: a conceptual framework. *Sustainability* **4**, 656–681 (2012).
53. Shue, H. Subsistence emissions and luxury emissions. *Law Policy* **15**, 39–59 (1993).
54. Shue, H. *Basic Rights: Subsistence, Affluence and U. S. Foreign Policy* (Princeton Univ. Press, 1980).
55. Caney, S. Cosmopolitan justice, responsibility, and global climate change. *Lei. J. Int. Law* **18**, 747–775 (2005).
56. Funk, A. & Sovacool, B. K. Wasted opportunities: resolving the impasse in United States nuclear waste policy. *Energy Law J.* **34**, 113–147 (2013).
57. *Current Status of Spent Nuclear Fuel* ANA Information Sheet (Australian Nuclear Association, 2015).
58. Sovacool, B. K. & Funk, A. Wrestling with the hydra of nuclear waste storage in the United States. *Electric. J.* **26**, 67–78 (2013).
59. Weinberg, A. M. Social institutions and nuclear energy. *Science* **177**, 27–34 (1972).
60. Weinberg, A. M. Immortal energy systems and intergenerational justice. *Energy Policy* **13**, 51–59 (1985).
61. Shue, H. in *Perspectives on Climate Change: Science, Economics, Politics, Ethics* (eds Sinnott-Armstrong, W. & Howarth, R. B.) 265–283 (Elsevier, 2005).
62. Nolt, J. in *The Ethics of Global Climate Change* (ed. Arnold, D. G.) 61–76 (Cambridge Univ. Press, 2011).
63. Barry, B. in *Obligations to Future Generations* (eds Sikora, R. & Barry, B. M.) 204–248 (Temple Univ. Press, 1978).
64. Barry, B. in *Energy and the Future* (eds MacLean, D. & Brown, P. G.) 15–30 (Rowman and Littlefield, 1983).
65. Barry, B. in *Democracy, Power, and Justice: Essays in Political Theory* (ed. Barry, B.) 511–525 (Clarendon, 1989).
66. deShalit, A. *Why Posterity Matters: Environmental Policies and Future Generations* (Routledge, 1995).
67. Ash, J. New nuclear energy, risk, and justice: regulatory strategies for an era of limited trust. *Polit. Policy* **38**, 255–284 (2010).
68. Shrader-Frechette, K. *What will Work: Fighting Climate Change with Renewable Energy, not Nuclear Power* (Oxford Univ. Press, 2011).
69. Bodde, D. L. in *Energy and the Future* (eds MacLean, D. & Brown, P. G.) 120–128 (Rowman and Littlefield, 1983).
70. Prouty, A. E. The clean development mechanisms and its implications for climate justice. *Columbia J. Environ. Law* **34**, 513–540 (2009).
71. Hope, C. How deep should the deep cuts be? Optimal CO₂ emissions over time under uncertainty. *Clim. Policy* **9**, 3–8 (2009).
72. de Bruin, K., Dellink, R. & Agrawala, S. *Economic Aspects of Adaptation to Climate Change: Integrated Assessment Modeling of Adaptation Costs and Benefits* (OECD, 2009).
73. Gupta, J. et al. in *Making Climate Change Work for Us: European Perspectives on Adaptation and Mitigation Strategies* (ed. Neufeldt, M. H. H.) 319–339 (Cambridge Univ. Press, 2010).
74. Peake, S. & Smith, J. *Climate Change: from Science to Sustainability* (Oxford Univ. Press, 2009).
75. IPCC *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (Cambridge Univ. Press, 2012).
76. Frumhoff, P., Heede, R. & Oreskes, N. The climate responsibilities of industrial carbon producers. *Climatic Change* **132**, 157–171 (2015).
77. *Climate Change and Human Rights: a Rough Guide* (International Council on Human Rights Policy, 2008).
78. Gardiner, S. M. in *Climate Ethics: Essential Readings* (eds Gardiner, S. et al.) 3–35 (Oxford Univ. Press, 2010).
79. Neumayer, E. In defence of historical accountability for greenhouse gas emissions. *Ecol. Econ.* **33**, 185–192 (2000).
80. Eriksen, S. et al. When not every response to climate change is a good one: identifying principles for sustainable adaptation. *Clim. Dev.* **3**, 7–20 (2011).
81. Brulle, R. J. & Antonio, R. J. The Pope's fateful vision of hope for society and the planet. *Nature Clim. Change* **5**, 900–901 (2015).
82. Carvalho, A. The Pope's encyclical as a call for democratic social change. *Nature Clim. Change* **5**, 905–907 (2015).
83. Singer, P. *Practical Ethics* (Cambridge Univ. Press, 1993).
84. International Energy Agency, United Nations Development Programme & United Nations Industrial Development Organization *Energy Poverty: How to Make Modern Energy Access Universal?* (OECD/IEA, 2010).

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Competing interests

The authors declare no competing financial interests.

STATE OF MICHIGAN

BEFORE THE MICHIGAN PUBLIC SERVICE COMMISSION

In the matter of the application of **DTE
ELECTRIC COMPANY** for authority to
increase its rates, amend its rate schedules
and rules governing the distribution and
supply of electric energy, and for
miscellaneous accounting authority

Case No. U-21534

ALJ Sally Wallace

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I, Mark N. Templeton, certify that an electronic copy of the Official Exhibits DAO-214 to DAO-224 sponsored by Yunus Kinkhabwala (Part 6 of 10) on Behalf of Soulardarity and We Want Green, Too was served on the following on September 12, 2024.

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