

Supplementary Information

Evaluating technology upgrades as a complement to traditional bill assistance programs

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Contents

Supplementary Table 1	3
Supplementary Table 2	5
Supplementary Table 3	6
Supplementary Table 4	6
Supplementary Table 5	7
Supplementary Table 6	8
Supplementary Table 7	8
Supplementary Table 8	8
Supplementary Figure 1	9
Supplementary Figure 2	10
Supplementary Figure 3a	11
Supplementary Figure 3b	12
Supplementary Figure 3c	13
Supplementary Figure 3d	14
Supplementary References	15

Supplementary Table 1

Table SI.1: State level sample information

<i>STATE</i>	<i>TOTAL HOUSEHOLDS</i>	<i>TOTAL OWNER-OCCUP. HOUSEHOLDS (OOHH)</i>	<i>TOTAL LOW-INC OOHH (<80% AMI) (LIHH)</i>	<i>MEDIAN LIHH ENERGY BURDEN</i>	<i>MEDIAN LIHH ANNUAL ENERGY COST</i>	<i>TOTAL LIHH EB>6%</i>
AL	9,105	5,168	2,044	11.3%	\$2,863	1,749
AR	5,528	3,044	1,154	10.9%	\$2,651	970
AZ	12,004	6,592	2,392	7.4%	\$2,271	1,512
CA	57,367	28,786	10,406	5.1%	\$2,255	4,431
CO	9,415	5,520	2,041	5.4%	\$2,269	891
CT	6,162	3,656	1,247	9.1%	\$4,368	926
DC	1,264	476	116	3.8%	\$1,946	41
DE	1,723	1,023	367	7.5%	\$2,641	224
FL	37,658	20,073	7,706	7.4%	\$2,150	4,912
GA	17,127	9,437	3,367	9.4%	\$2,820	2,604
IA	5,616	3,619	1,327	8.7%	\$2,947	969
ID	2,828	1,712	608	5.8%	\$1,633	293
IL	21,870	13,050	4,664	8.0%	\$2,889	3,177
IN	11,672	7,149	2,591	9.9%	\$3,068	2,117
KS	5,147	3,025	1,054	10.7%	\$3,572	909
KY	8,040	4,694	1,795	11.8%	\$2,906	1,536
LA	8,302	4,574	1,759	10.3%	\$2,439	1,423
MA	11,690	6,557	2,208	9.1%	\$4,314	1,608
MD	9,973	5,968	2,123	5.0%	\$2,398	866
ME	2,997	1,634	637	13.2%	\$4,283	540
MI	18,744	11,381	4,326	8.9%	\$2,798	3,212
MN	9,816	6,292	2,389	7.6%	\$3,170	1,501
MO	11,285	6,535	2,473	9.7%	\$2,968	1,913
MS	5,336	2,997	1,179	11.4%	\$2,514	1,043
MT	2,027	1,141	443	7.5%	\$2,307	276
NC	18,369	10,234	3,834	8.5%	\$2,380	2,675
ND	1,441	778	292	10.4%	\$3,787	237
NE	3,364	2,016	686	9.0%	\$3,150	531
NH	2,555	1,501	507	10.5%	\$4,746	406
NJ	14,783	8,429	2,619	5.1%	\$2,281	1,073
NM	3,762	2,114	814	8.8%	\$2,040	568
NV	4,946	2,420	828	6.3%	\$2,096	431
NY	33,676	15,973	5,818	9.0%	\$3,837	4,152
OH	21,219	12,533	4,486	9.2%	\$2,966	3,405
OK	7,007	3,903	1,495	11.6%	\$3,200	1,314
OR	7,025	3,998	1,389	5.1%	\$1,826	543

PA	23,052	14,029	5,060	8.7%	\$2,783	3,526
RI	1,910	1,023	327	11.0%	\$3,975	269
SC	9,029	5,246	2,047	9.2%	\$2,507	1,553
SD	1,546	919	338	9.2%	\$3,174	256
TN	11,834	6,842	2,489	9.1%	\$2,473	1,902
TX	43,058	23,435	8,261	8.2%	\$2,605	5,766
UT	4,224	2,643	845	4.2%	\$1,734	242
VA	14,180	8,362	2,772	7.4%	\$2,745	1,696
VT	1,345	741	278	12.6%	\$4,432	236
WA	12,224	7,039	2,375	4.5%	\$1,847	798
WI	10,917	6,392	2,305	8.3%	\$2,925	1,596
WV	3,648	2,168	897	10.6%	\$2,557	719
WY	1,106	639	232	8.7%	\$3,090	177
ALL	548,916	307,480	111,410	8.0%	\$2,653	73,714

Supplementary Table 2

Table SI.2: Percent of Income Payment Plan design across the United States

	PROGRAM	ELIGIBILITY	SOURCE
OH	This permanent program is one of the longest-running in the U.S. Monthly customer payment is fixed at 5% of gross income for natural gas and 5% for electric (10% if electric heat). Minimum bill of \$10/month. 24 on-time and in-full payments eliminates outstanding balance. Annual income verification. Costs range depending on weather from low of \$292.5M in 2012 to high of \$405.5M in 2010. ¹ In 2015, there were 386,491 customers and payments totaled \$304M for electric and \$28M for gas. ²	175% FPL	OH Dept. of Development ³ OH PUC Case: 13-0274-AU-ORD ⁴
NJ	Universal Service Fund is a statewide NJ Dept. of Human Services program that caps gas and electric bill at 6% of annual income. Annual cap at \$1,800/year.	60% SMI	NJ Dept. of Community Affairs USF fact sheet and FAQs ⁵
IL	Permanent program that caps gas and electric bills at 6% of their income. Includes an arrearage forgiveness aspect in addition, requiring on time payments. There is a maximum benefit of \$1,800 per year (monthly maximum of \$100 for gas, \$50 for electric). In FY 2015, 55,860 households received almost \$55M.	150% FPL	Summary on LIHEAP Clearinghouse ⁶
NV	Permanent program that aims to provide assistance to qualifying households such that their energy burden is capped at the state median (determined annually) via an annual, one-time benefit paid to the energy provider. Program caps depend on FPL level and also take into account household members at or above 60 years old, disabled, or child less than 6 years old. Additionally account for oil or propane primary energy sourced homes. 19,394 households were served in 2021 and were awarded \$7,715,759 (total expenditures were \$8,844,556)	150% FPL	SFY 2021 Evaluation: Energy and Weatherization Assistance Programs ⁷
CA	Four year pilot programs (started 2023) for gas and/or electric customers. A monthly bill cap is set (additional to taxes, fees, and past due amounts) roughly based on 4% of gross income and subject to change on a yearly basis. The CA decision that applies to all three CA investor-owned utilities specifies a cap of 15,000 participants and estimated costs of \$23M of subsidies over four years. - SDG&E pilot can accept 1,000 customers with a cap of \$38 (0-100% FPL) or \$115 (100-200% FPL) - PG&E pilot can accept 5,000 customers with a cap of \$29 (electric) and \$9 (gas) (0-100% FPL) or \$86 (electric) and \$29 (gas) (100-200% FPL) SCE pilot can accept 4,000 customers offers a cap of \$29 (0-100% FPL) or \$86 (100-200% FPL)	Enrolled in CARE (200% FPL) and disconnected 2+ times due to nonpayment between 3/2019 - 2/2020; located in specific zip codes with high levels of disconnection	SDG&E ⁸ PG&E ⁹ SCE ¹⁰ CA PUC Decision 21-10-012 ¹¹
CONSUMERS ENERGY (MI)	Two-year pilot program (started Oct, 2022) for 1,500 gas and/or electric customers whose bills will be fixed at 6% of gross income (\$10/month minimum bill) in addition to arrear forgiveness. Estimated cost per year is \$1.75M.	150% FPL	MI PSC Case: U-21021 ¹²

Supplementary Table 3

Table SI.3: Share of owner-occupied low-income households that are weatherization and/or solar ready along with median capital costs on one side and bill savings (and consequent energy burden point reduction) on the other

	High energy burden (>6%) Low-Inc Household Potential	Mean Solar Size [kW]*	Median Capital Cost**	Median Year 1 Bill Savings	Median Energy burden point reduction
<i>PiPP</i>	73,714 (100%)			\$1,373	4.5
<i>Wx</i>	72,812 (99%)		\$1,237	\$592	2.3
<i>Solar</i>	71,388 (97%)	4.6 kW	\$12,074	\$998	3.7
<i>Wx+Solar</i>	73,714 (100%)	4.5 kW	\$13,729	\$1,585	6
<i>*Weatherization measures remain the same for Wx+solar case, but presence of weatherization reduces average annual electricity demand constraint for a subset of participating low-income households, which reduces the mean system size</i> <i>** Costs reflect addition of state and federal tax incentives (see Methods)</i>					

Supplementary Table 4

Table SI.4: Solar system size constraints for energy burdened, solar-ready, owner-occupied low-income households (excludes multifamily or any household without access to rooftop)

	PV	Electric share of cost [% of all low-inc households (LIHH)]	Electric share of cost [% of all solar LIHH]	Share of 5 kW solar systems	Share with rooftop constraint	Share with avg. annual load const
<i>Midwest</i>		46%	44%	56%	2%	43%
<i>Northeast</i>		43%	36%	53%	2%	45%
<i>South</i>		81%	80%	87%	1%	11%
<i>West</i>		73%	72%	55%	1%	44%
<i>All</i>		65%	62%	69%	1%	30%
	<i>Wx+PV</i>	Electric share of cost [% of all LIHH]	Electric share of cost [% of all solar LIHH with high energy burden]	Share of 5 kW solar systems	Share with rooftop constraint	Share with avg. annual load const
<i>Midwest</i>		49%	47%	49%	1%	50%
<i>Northeast</i>		46%	41%	46%	2%	52%
<i>South</i>		78%	78%	82%	1%	17%
<i>West</i>		70%	70%	48%	1%	51%
<i>All</i>		64%	62%	62%	1%	36%

Supplementary Table 5

Table SI.5: Weatherization measures considered (from NREL's End Use Savings Shapes and cost database)¹³

Summary of Measure	Detailed Measure	Cost (Range) ¹⁴	Sample Share (Mean Cost where Applied)
<i>Attic floor insulation up to IECC-Residential 2021 levels for dwelling units with vented attics and lower-performing insulation</i>	Applies only to dwelling units with vented attics	\$0.76/ft² of attic floor area (\$0.46 - \$0.99)	84% (\$1,008)
	R-30 if... - IECC climate zone 1A - R-13 or less		
	R-49 if... - IECC climate zones 2A, 2B, 3A, 3B, 3C - R-30 or less		
<i>General air sealing: 30% total reduction in ACH50 for dwelling units with greater than 10 ACH50</i> <i>Duct sealing to 10% leakage, R-8 insulation</i>	R-60 if... - IECC CZ 4A, 4B, 4C, 5A, 5B, 6A, 6B, 7A, 7B - R-38 or less		
	30% whole-home reduction in ACH50 if... 15 ACH50 or higher infiltration	\$1.20/ft² of finished floor area (\$0.48 - \$1.80)	71% (\$1,818)
	10% Leakage, R-8 if... Leakier and/or less insulated ducts (than 10% or R-8) located in unconditioned space	\$0.40/ft² of ducts if 20% leakage (\$0.20 - \$0.59) \$0.81/ft² of ducts if 30% leakage (\$0.40 - \$1.20)	47% (\$294)
<i>Drill-and-fill insulation (R-13) for dwelling units with no insulation and wood stud walls</i>	R-13 insulation with wood stud walls if... Uninsulated wood stud walls	\$2.20/ft² of exterior wall area above grade (\$1.20 - \$2.90)	38% (\$3,622)
<i>Add R-10 interior insulation to foundation walls and rim joists in conditioned basements and crawlspaces; seal crawlspace vents</i>	R-10 interior insulation for foundation walls and rim joists if... - Unvented crawlspaces, vented crawlspaces, or heated basements - Has no foundation wall insulation	\$1.70/ft² of wall area below ground if crawlspace (\$1.20 - \$2.20) \$3.10/ft² of wall area below ground if heated basement (\$2.30 - \$4.00) \$1.80/ft² of rim joist area (\$1.20 - \$2.30)	33% (\$1,622)
<i>Insulate finished attics and cathedral ceilings to R-30</i>	R-30 roof insulation if... - Single-family, or top-level multi-family unit - Roof insulation of R-13 or less - Has finished attics or cathedral ceilings	\$4.30/ft² of roof area (\$2.60 - \$5.50)	0.3% (\$5,475)
Total			98% (\$4,290)

Supplementary Table 6

Table SI.6: Maximum rooftop solar to load ratio allowed, by state, derived from Energy Sage public data.¹⁵

Values are used to set one of the three rooftop solar system size constraints (see “Methods”). “All” value is applied if state does not have its own value listed in this table.

STATE	PV-TO-LOAD RATIO
AZ	1.02
CA	1.06
FL	1.00
GA	0.83
IL	1.00
MA	0.95
NC	0.94
NJ	0.93
NV	1.00
NY	0.95
TX	0.96
VA	0.92
ALL	1.00

Supplementary Table 7

Table SI.7: Rooftop solar cost per Watt derived from Berkeley Lab’s Tracking the Sun¹⁶ after filtering out any (1) third-party owned, (2) self-installed, (3) expansions, and (4) non-residential systems; and filtering for (5) solar-only, (6) install date in 2022, and (7) cash purchased. This does not take into account any state or federal tax incentives.

REGION	MEDIAN \$/W	MEAN \$/W	ST. DEV. \$/WATT	N
MIDWEST	3.009	3.241	1.024	1,387
NORTHEAST	3.722	4.34	1.890	7,884
SOUTH	3.555	3.983	1.609	592
WEST	3.206	3.450	1.115	20,318

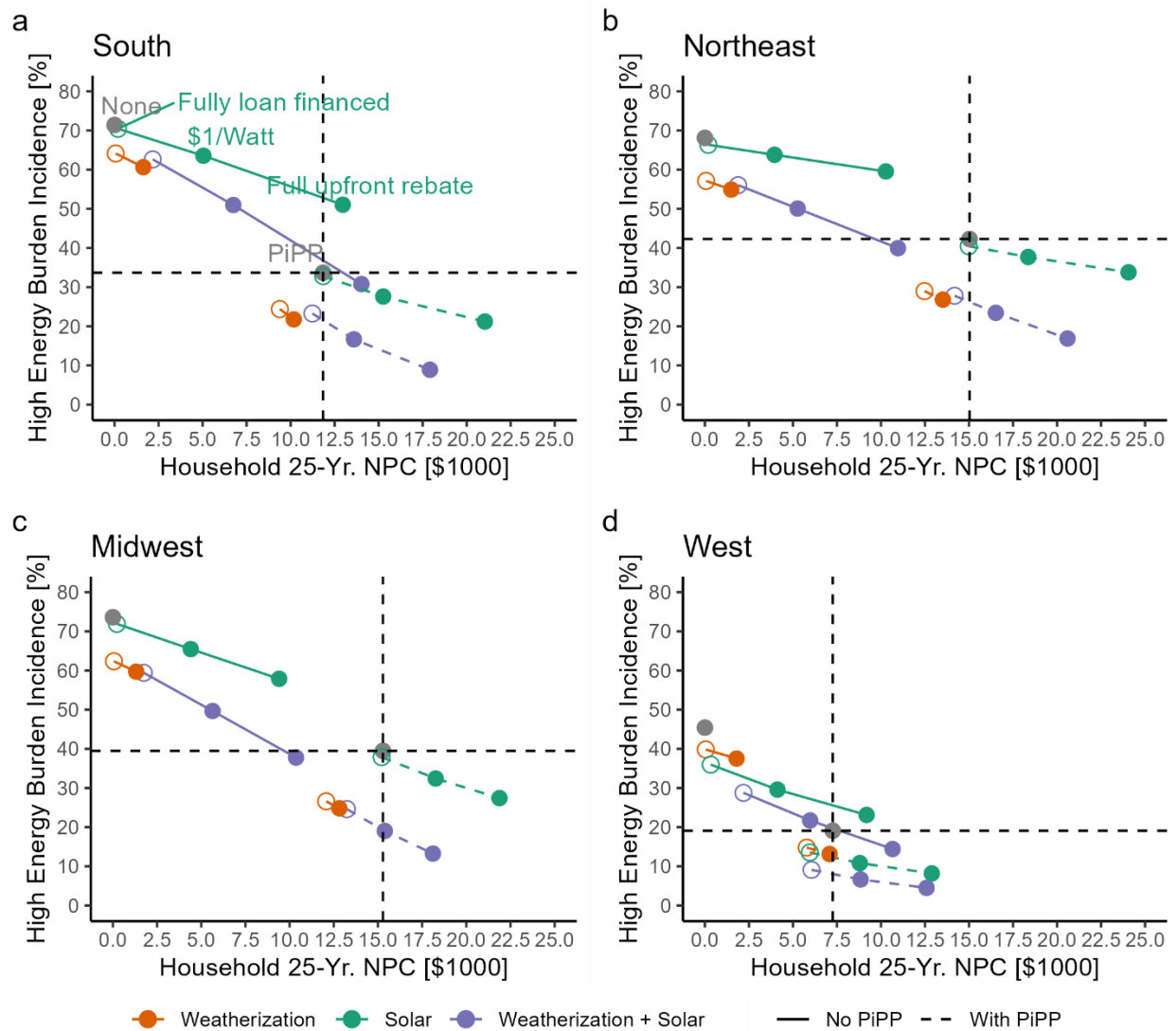
Supplementary Table 8

Table SI.8: Active state investment tax credits used in the main analysis (removed in sensitivity without tax credit)

	State ITC Level	Max. Incentive Level
AZ	25%	\$1000
MA	15%	\$1000
NY	25%	\$5000
NM	10%	\$6000

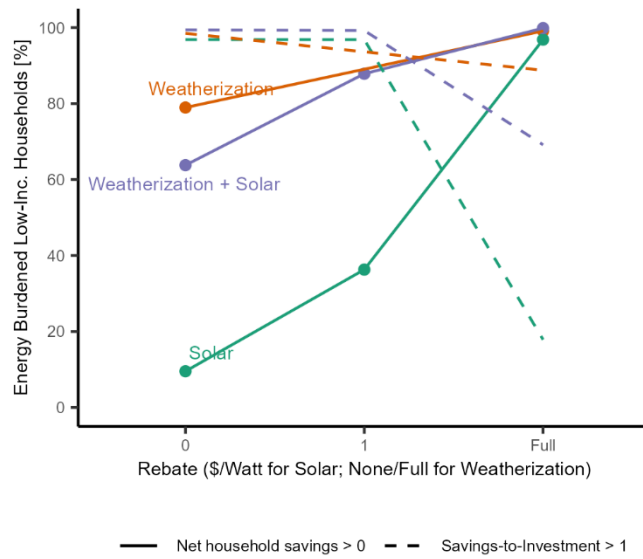
Supplementary Figure 1

Figure SI.1: Regional comparison of various program designs: *Dotted lines include the installed measures with percent of income payment plan (PiPP). Line segments represent changes moving (left to right) from fully loan-financed (empty circle) to a full upfront rebate. For the weatherization + solar case, weatherization is fully rebated. Dotted axes show efficacy and NPC of PiPP. Thus, points in the upper-left quadrant are cheaper, but less effective; lower-left are both cheaper and more effective; lower-right are more expensive and more effective when compared to PiPP alone.*



Supplementary Figure 2

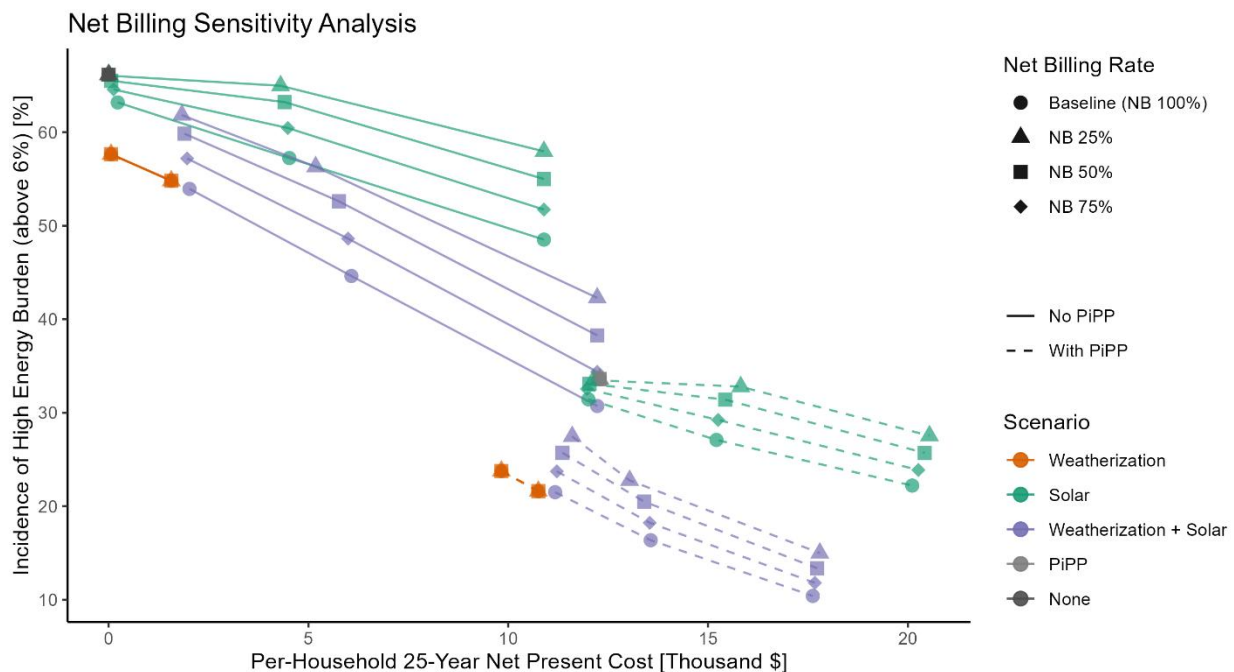
Figure SI.2: Cost effective share of eligible households as a function of incentive level, without federal or state tax incentives: *Dotted line follows share of household investments that yield savings-to-investment ratio (SIR) over 1 (cost effective from program perspective) while solid line follows share of household investments that yield positive net savings (cost effective from household perspective). The rebate levels for weatherization go from zero to full, while that for solar include intermediate \$/Watt levels. For the combination of solar and weatherization, weatherization is fully rebated while solar is incentivized at varying levels.*



Supplementary Figure 3a

Figure SI.3a: Sensitivity to solar tariffs: Comparing net metering to net billing under varying net export compensation levels. Results show each variation with and without bill assistance and under each combination of bill assistance, weatherization, and solar programming.

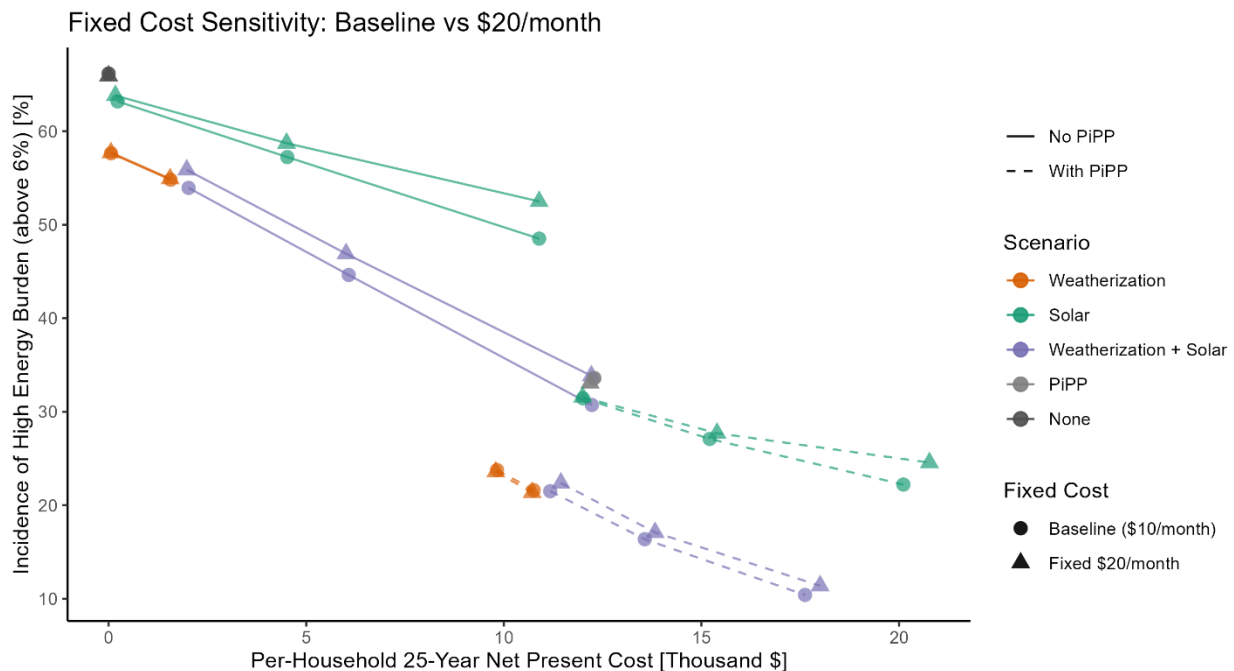
Notes: For the main analysis, net metering is assumed as it is in effect in the majority of states in the country at present (see Methods). However, states have begun to explore other solar tariff structures, including net billing where solar net exports are compensated at a fraction of retail prices. We explore this impact by looking at net exports being compensated at 100% of retail prices (i.e., net metering) compared to 25%, 50%, and 75% of retail price levels. We assume net exports, netted hourly, to be 64% based on a previous study that used modeled solar sized to meet average annual load for 2,919 customers across the U.S. with empirical meter data.¹⁷ The baseline, PiPP alone, and Weatherization cases remain unchanged, however, the Solar and Solar + Weatherization both become more expensive as well as less effective. Net present cost goes up, but only slightly because the value is dominated by any upfront rebate offered, which remains the same since the capital cost of the panels are unchanged. The bigger impact occurs with the ability to reduce incidence of high energy burden. For example, in the main analysis under net metering, fully rebated Weatherization + Solar reduced high energy burden incidence 3 percentage points over PiPP alone. At 75% retail compensation for net exports, this same combination performed 0.8 points worse than PiPP alone, though at a slightly cheaper NPC. However, at 50% and 25% compensation, performance was 4.7 and 8.7 points worse, respectively.



Supplementary Figure 3b

Figure SI.3b: Sensitivity to electricity costs recovered via fixed charges: Comparing \$10 per month in fixed charges (as used in the study) to \$20. Results show each variation with and without bill assistance and under each combination of bill assistance, weatherization, and solar programming.

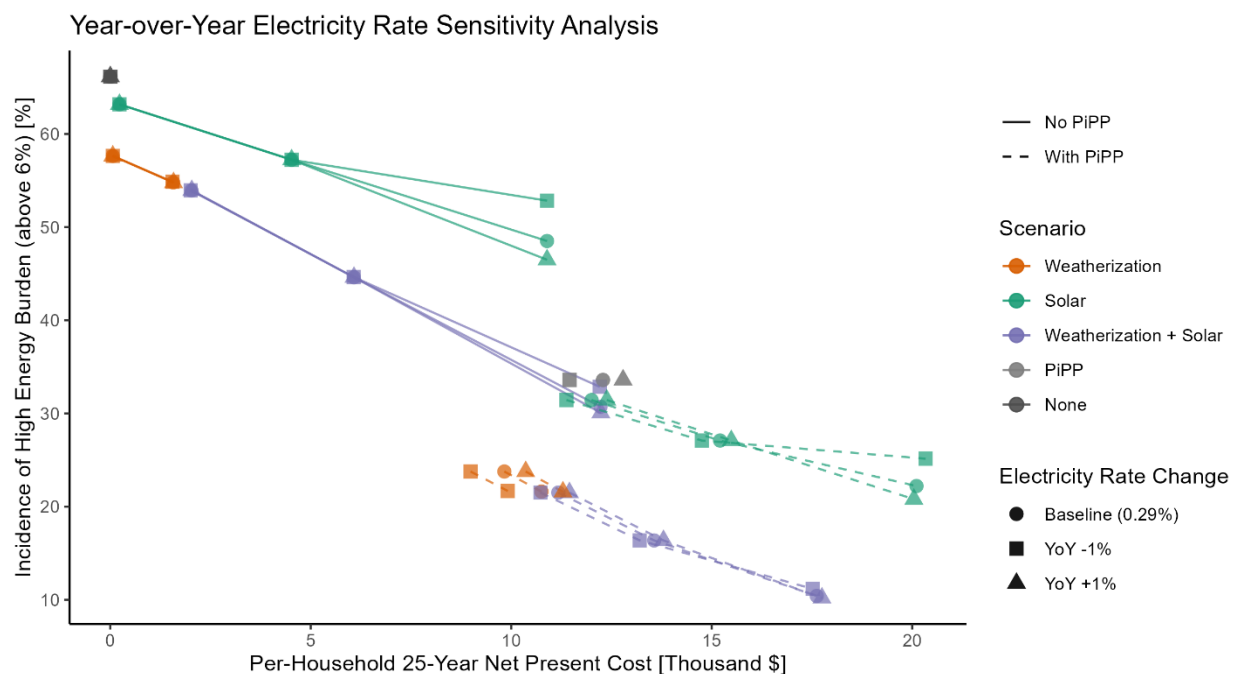
Notes: For the main analysis, we assume \$10 per month are charged to each household for electricity and the rest of the costs are recovered in a volumetric \$/kilowatt-hour rate (see “Electricity prices” in “Methods”). We explore a higher fixed cost of \$20 per month. This reduces the customers’ volumetric rates very slightly, which impacts both weatherization and solar efficacy. However, the bigger impact is that an additional \$10 per month cannot be offset by electricity savings or generation. This has a bigger impact on solar in homes where the system is sized to offset total annual consumption, and can subsequently increase energy burden (and efficacy). Indeed, the Weatherization + Solar case with \$10/month reduced high energy burden incidence 3 percentage points over PiPP alone, but with \$20/month fixed charges this drops to 0.8 points worse than PiPP alone. When PiPP is combined with installed measures, PiPP becomes relatively more expensive because the weatherization and solar don’t offset as much of the electricity bill. This is why the dotted lines are shifted both up and to the right whereas the solid lines are only shifted up.



Supplementary Figure 3c

Figure SI.3c: Sensitivity to electricity rate trends: Comparing performance under electricity rates that fall 1% year-over-year (accounting for inflation) versus those that increase 1%. Results show each variation with and without bill assistance and under each combination of bill assistance, weatherization, and solar programming.

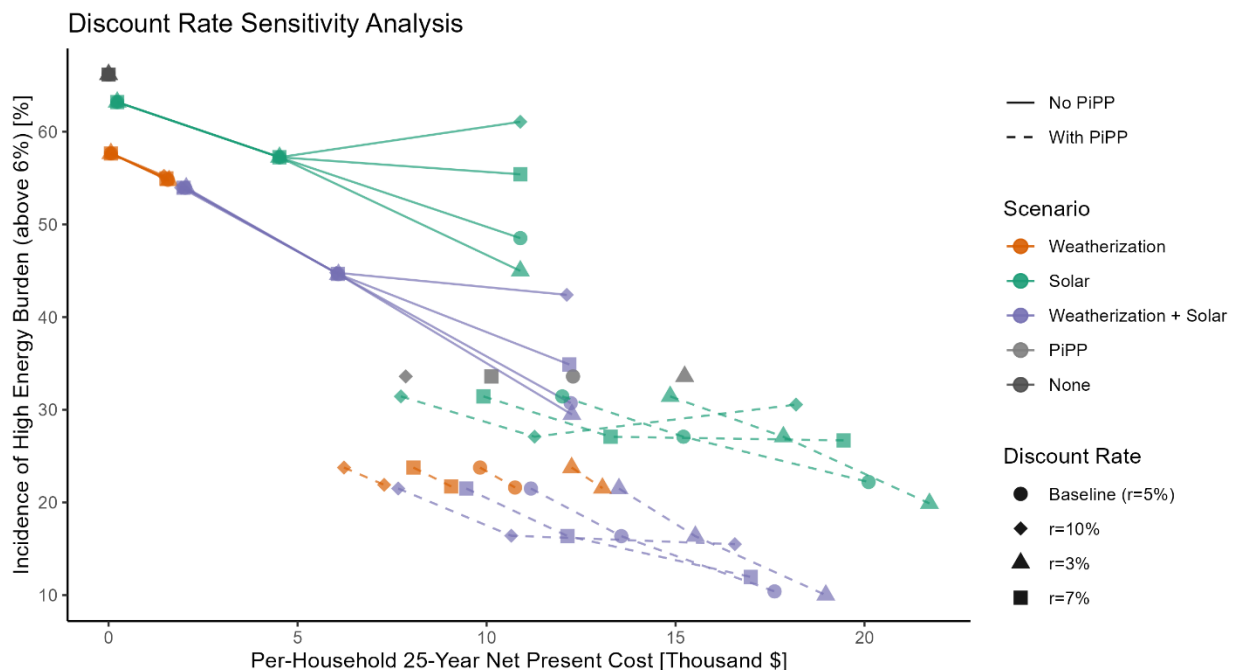
Notes: For the main analysis, we assume 0.29% increase in residential rates year-over-year, accounting for inflation. This impacts the net present cost of PiPP as well as the net present value of bill savings from installed measures, which impacts the savings-to-investment ratio that the program requires to be over 1.0 in order to provide upfront incentives and determine eligibility. As a result, the grey PiPP baseline point shifts left (for 1% decreasing electricity rates) or right (for 1% increasing rates), impacting the comparative performance of the programs examined. There is also a large shift in the efficacy of programs at the full rebate level. Under decreasing rates, net present savings of installed measures go down, however, the upfront capital cost required remains the same. Thus, fewer households qualify for these high rebate levels due to the SIR above 1.0 requirement, and they do not benefit from participating (i.e., point goes down). Additionally, if fewer households participate, the program gets slightly cheaper to administer (i.e., point goes to the left) and vice versa. At the \$1/Watt level, participation remains fairly unchanged. Also notable, the combination of all strategies (PiPP + Weatherization + Solar) remains fairly insensitive to these changes, demonstrating that a diverse set of programs can offer robust bill reduction both in the present and future.



Supplementary Figure 3d

Figure SI.3d: Sensitivity to discount rate varying levels incrementally from 3% to 10%. Results show each variation with and without bill assistance and under each combination of bill assistance, weatherization, and solar programming.

Notes: For the main analysis, we assume a 5% discount rate, which impacts the net present cost of PiPP and the net present value of bill savings from installed measures. Similar to Figure SI.3c (sensitivity to electricity rate trends), this impacts participation due to the requirement that SIR be greater than 1.0. Again, at the full rebate level, there is a big drop in participation (i.e., cost effective program investment), so the efficacy decreases with higher discount rates (i.e., points go up). PiPP net present cost is far more impacted than with the electricity rate change and drastically changes. Compared to the NPC of the main analysis using a 5% rate, discount rates of 7% and 10% decrease NPC 18% and 36%, respectively while a 3% rate increases NPC 24%. This impacts the efficacy of installed measure programs alone, making them relatively cheaper under lower discount rates and vice versa.



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