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July 26, 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 Accompanying Exhibits DAO-108 to DAO-117 (Part 2 of 5) for the Direct Testimony of Justin Schott 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".

Mark N. Templeton, *pro hac vice*
6020 S. University Avenue
Chicago, IL 60637
Phone: (773) 702-9611
Email: templeton@uchicago.edu

xc: Parties to Case No. U-21534

Billing

Frequently Asked Questions

Low-Income Self-Sufficiency Plan (LSP)

Who is eligible for the Low-Income Self-Sufficiency Plan?

How is the LSP monthly payment amount determined?

The monthly payment amount is determined by the customer's income level, usage and type of active electric or natural gas service.

What is the enrollment period?

Can I get State Emergency Relief (SER) assistance from the Michigan Department of Health and Human Services (MDHHS) after joining the program?

- ⌵ Can I file for a Home Heating Credit after enrolling in the program?
- ⌵ Can I receive assistance from other human services agencies after enrolling in the program?
- ⌵ What happens if I move after joining the program?
- ⌵ What happens if I miss payments while enrolled in the program?
- ⌵ If I'm enrolled in the Home Protection Plus (HPP) program am I eligible to enroll in the LSP?
- ⌵ What happens if I am removed from the program? Am I still eligible for MDHS assistance?
- ⌵ How long does the LSP last?
- ⌵ Can I have more than one account enrolled in the LSP?
- ⌵ Do I have to be a primary account holder to enroll in the LSP?
- ⌵ How do I enroll in the LSP program?

Low-Income Self-Sufficiency Plan

Our Low-Income Self-Sufficiency Plan is a payment plan for vulnerable families to make affordable monthly payments based on income. At this time, State Emergency Relief (SER) is not available until October 1, 2024, so applicants are not required to apply for an SER to qualify for the plan.

Benefits

- Shutoff protection while on the plan
- Affordable fixed monthly payments based on your income and energy usage
- Elimination of any future late payment charges while you remain on the plan
- Receive energy assistance funds from the State of Michigan and/or DTE to help lower your monthly bill
- Past-due energy charges are now frozen and reduced monthly with a forgiveness credit
- Dedicated DTE Customer Advocates ready to assist you

Requirements

- Must make your fixed monthly bill payment on time
- Monitor, maintain and/or reduce, when possible, your energy usage
- Call us at (800) 317-9073 if you are having trouble making your payments

Federal & State Eligibility Criteria

The eligibility requirements are defined according to federal and state energy assistance criteria.

- Income is equal to or less than 150% of the Federal Poverty Level Guidelines
- Energy usage (electric and/or gas) over the last 12 months is comparable with average annual usage for a residential customer

Application & Enrollment Process

This 24-month plan requires household income verification and energy usage validation every year for all participating customers. To learn what documents are required for the income verification, watch this video.

If you are interested in enrolling in this plan, please contact one of our energy assistance agencies who will perform income and usage eligibility validation for this plan.

If you have any questions or concerns, please contact our Energy Advocacy Group at (800) 317-9073 during business hours Monday to Friday, 8:30 a.m. to 5:00 p.m.

Low-Income Self-Sufficiency Plan FAQ

fpl	energy_bu	energy_bu	h_count	total_h_co	percent
0-100%	3-6%	Affordable	303	283803	0.106764
0-100%	6-9%	Moderatel	5205	283803	1.834019
0-100%	9-12%	High	28863	283803	10.17008
0-100%	12-15%	Severe	47610	283803	16.77572
0-100%	15-20%	Extreme	76562	283803	26.97716
0-100%	20%+	Catastroph	125260	283803	44.13625
100-150%	0-3%	Inexpensiv	456	191328	0.238334
100-150%	3-6%	Affordable	34011	191328	17.77628
100-150%	6-9%	Moderatel	93895	191328	49.07541
100-150%	9-12%	High	50676	191328	26.48645
100-150%	12-15%	Severe	10599	191328	5.539701
100-150%	15-20%	Extreme	1691	191328	0.883823
150-200%	0-3%	Inexpensiv	4756	208211	2.284221
150-200%	3-6%	Affordable	120030	208211	57.64825
150-200%	6-9%	Moderatel	75055	208211	36.04757
150-200%	9-12%	High	8134	208211	3.906614
150-200%	12-15%	Severe	236	208211	0.113347
200-400%	0-3%	Inexpensiv	329025	747653	44.00771
200-400%	3-6%	Affordable	403844	747653	54.0149
200-400%	6-9%	Moderatel	14784	747653	1.977388
400%+	0-3%	Inexpensiv	1010910	1015747	99.5238
400%+	3-6%	Affordable	4837	1015747	0.476201

% of MI Households < 150% FPL 19.40%

SOURCE: DOE LEAD Tool <https://www.energy.gov/scep/slsc/lead-tool>



Utility Redlining: Inequitable Electric Distribution in the DTE Service Area

WE THE PEOPLE MICHIGAN with Souldardarity & MEJC

POLICY & RESEARCH BRIEF

August // 2022

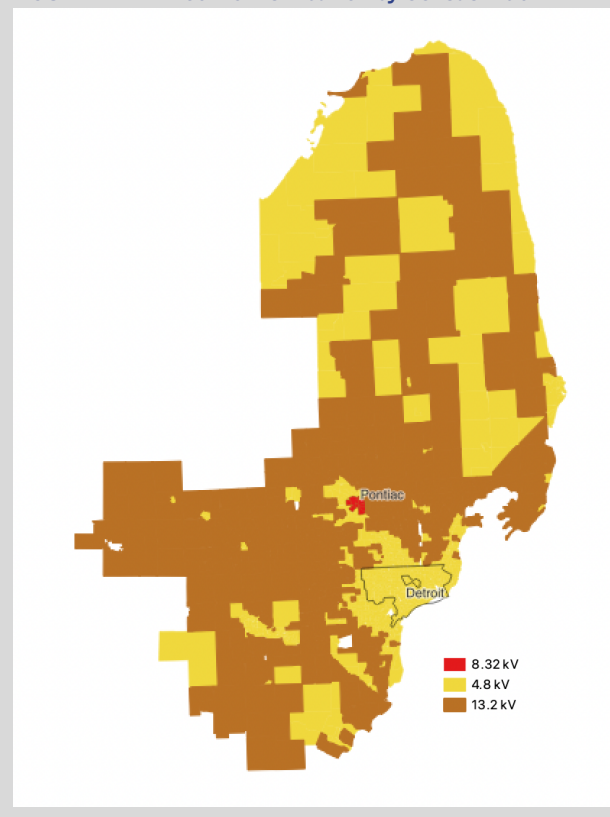
INTRODUCTION

The U.S. has a long history of discrimination when it comes to housing. The practice of denying a home loan based on the race of the neighborhood, or redlining, is the best known example. However, racist practices in housing have led to similar racial disparities in future home mortgages, broadband internet, and retail amenities.¹ Utilities are no different when it comes to employing racial discrimination in the supply and distribution of energy.

BACKGROUND

The Sierra Club found that redlining and systemic racism have significant effects on climate impacts among minority communities.² A study of 108 urban areas in the U.S. found 94% of formerly redlined areas were 7 degrees warmer than non-redlined areas.³ Extreme heat and energy burdens impact minority communities the most with rates of death from extreme heat highest among Black and elderly individuals.⁴ Energy infrastructure and electric

FIGURE 1: DTE Electric Distribution by Census Tract



distribution are critical elements of providing adequate service to vulnerable populations.

KEY POINTS:

1. Key DTEE infrastructure is a decade or more past expected use in 4.8 kV areas
2. In Detroit, with double the vulnerability level as the region, most residents only have outdated electric infrastructure
3. Modernization efforts in Detroit favor industrial and municipal customers over residents

¹Alex B. Hill, "Before Redlining and Beyond. How Data-Driven Neighborhood Classification Masks Spatial Racism", *Metropolitix*, 2 November 2021. URL : <https://metropolitix.org/Before-Redlining-and-Beyond.html>

²Sharonda Williams-Tack, "From Redlining to Restorative Justice: Anti-Black racism and energy insecurity go hand in hand in America", *Sierra Club*, 21 February 2021. URL: <https://www.sierraclub.org/sierra/redlining-restorative-justice>

³Hoffman, Jeremy S., Vivek Shandas, and Nicholas Pendleton. 2020. "The Effects of Historical Housing Policies on Resident Exposure to Intra-Urban Heat: A Study of 108 US Urban Areas" *Climate* 8, no. 1: 12. <https://doi.org/10.3390/cli8010012>

⁴Khatana, Sameed Ahmed M., Rachel M. Werner, and Peter W. Groeneveld. "Association of Extreme Heat With All-Cause Mortality in the Contiguous US, 2008-2017." *JAMA Network Open* 5, no. 5 (2022): e2212957-e2212957.



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Extreme heat and climate impacts are exacerbated by utility companies' high consumption of fossil fuels as well as their slow adoption of renewable energy. Researchers have found that there has been an inequitable investment in electric distribution systems that support greater adoption of distributed renewable energy, such as local wind and home solar for heating, cooling, or EV charging.⁵

Electrical Distribution

The DTE Electric (DTEE) Southeast Michigan retail service area (Figure 1) is a textbook example of the inequitable electric distribution system.

TABLE 1: Electric distribution broken down by demographics and Social Vulnerability Index

Indicator	8.32 kV	4.8 kV		13.2 kV
		Detroit	Out Detroit	
Tract Count	10	306	491	642
Percent minority	73.2	89.5	24.0	21.8
Percent poverty	33.8	38.0	14.6	9.5
Percent unemployed	14.3	18.2	6.2	5.3
Social vulnerability index (0-1) ⁶	0.89	0.82	0.43	0.35

⁵ Brockway, Anna M., Jennifer Conde, and Duncan Callaway. "Inequitable access to distributed energy resources due to grid infrastructure limits in California." *Nature Energy* 6, no. 9 (2021): 892-903.
⁶ CDC Social Vulnerability Index (SVI), 2018. URL: <https://www.atsdr.cdc.gov/placeandhealth/svi/index.htm>

DTEE predominantly underserves an area that has higher percentages of BIPOC and people experiencing poverty (see Table 1). Social vulnerability, or the potential negative effects on communities, as defined by the CDC is more than double the level where DTEE has left un-upgraded 4.8 kilovolt (kV) electric infrastructure compared to 13.2 kV areas.

TABLE 2: DTEE Average Age of Assets Compared to Industry Life Expectancy⁷

DTEE assets	Industry Life Expectancy	DTEE Avg Age	Avg Age 4.8 kV	Avg Age 13.2 kV
Substations	45	43	53	32
Network banks (transformers)	30	46	40	1
Switchgear	40	37	46	35
Poles and hardware	50	46	49	43
System cable	40	45	64	25

The areas served by 4.8 kV are subject to service inadequacies on numerous fronts identified in the testimony of Soulardarity and We Want Green Too in DTEE's 2022 rate increase case.⁸ Five categories of infrastructure assets are

⁷ Direct Testimony of Jackson Koeppel on Behalf of Soulardarity and We Want Green, Too, Before the Michigan Public Service Commission, State of Michigan (2022) (statement of Jackson Koeppel, independent consultant for Soulardarity) <https://mi-psc.force.com/sfc/servlet.shepherd/version/download/0688y000002y4SPAAY>
⁸ Ibid.



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substantially older (Table 2), in many cases a decade past their projected life expectancy. This contributes to lower reliability, longer restoration times, and dangerous downed wire conditions.⁹

Hosting Capacity

The 4.8 kV system is archaically behind on safety standards and does not integrate advanced technology like smart grid controls, solar, storage, and EV charging.¹⁰ All of these technologies are advantageous in reducing air pollution, building community wealth, and improving safety and reliability.

TABLE 3: Hosting Capacity of Different kV infrastructure in kilowatts (kW)¹¹

	4.8 kV	13.2 kV
Average Hosting Capacity	138 kW	989 kW
Median Hosting Capacity	150 kW	975 kW

⁹ Qualifications and Revised Direct Testimony of Sharon Pfeuffer, Before the Michigan Public Service Commission, State of Michigan (2022) (statement of Sharon Pfeuffer, Vice President of Distribution Operations Engineering and Construction, DTE) <https://mi-psc.force.com/sfc/servlet.shepherd/version/download/0688y000003NfHgAAK>

¹⁰ Qualifications and Revised Direct Testimony of Joy H. Wang, Ph.D., Before the Michigan Public Service Commission, State of Michigan (2022) (statement of Joy H. Wang, public utilities engineer in Electrical Operations Section, MPSC) <https://mi-psc.force.com/sfc/servlet.shepherd/version/download/0688y000002zRNRAA2>

¹¹ Direct Testimony of Jackson Koeppel on Behalf of Soulardarity and We Want Green, Too, Before the Michigan Public Service Commission, State of Michigan (2022) (statement of Jackson Koeppel, independent consultant for Soulardarity) <https://mi-psc.force.com/sfc/servlet.shepherd/version/download/0688y000002y4SPAAY>

The 4.8 kV systems are also ungrounded, leading to death by electrocution, as has been the subject of investigation by the Michigan Public Service Commission (MPSC). The relative ability of 4.8 kV systems to integrate clean and modern technology, and DTEE's failure to plan for near-term upgrades, condemns low-income and BIPOC communities to an expanding gap in technology access and service quality over the coming decades (Table 3).

Infrastructure Hardening: Detroit

The most common rebuttal to service failures is that DTEE is "hardening" its infrastructure, which could mean a wide range of activities from upgrading wires to trimming trees.

TABLE 4: Demographics of Areas on DTEE Hardening Schedule Compared to Modernization

Indicator	Modern-ization	Hardening		
		2018 - 2019	2020 - 2022	2023 - 2026
Tract Count	62	23	84	132
Percent minority	80.8	94.8	88.7	92.6
Percent poverty	38.2	35.3	13.8	38.1
Percent unemployed	14.5	16.3	17.1	19.6
Social vulnerability index (0-1) ¹²	0.78	0.82	0.87	0.82

¹² CDC Social Vulnerability Index (SVI), 2018. URL: <https://www.atsdr.cdc.gov/placeandhealth/svi/index.htm>



Utility Redlining: Inequitable Electric Distribution in the DTE Service Area

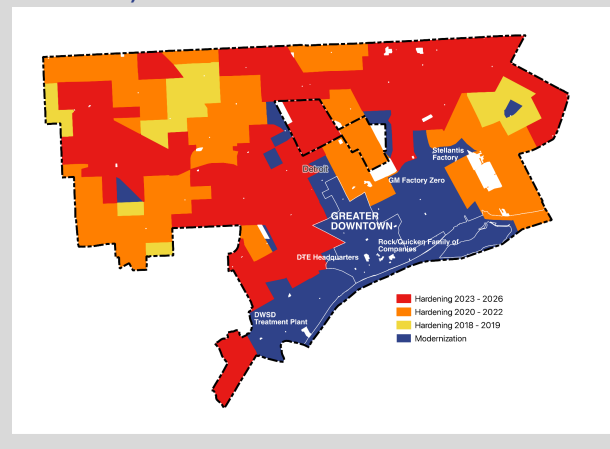
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The DTEE hardening schedule favors wealthier areas of Detroit as opposed to lower income areas. The alternative to hardening is the complete modernization of infrastructure. Yet modernization efforts in Detroit are concentrated in the Greater Downtown area. Hardening efforts initially targeted a much smaller area compared to the areas proposed for hardening after 2023 (23 vs. 132 Census Tracts, **Table 4**). The lowest priority area for hardening in Detroit has the highest poverty rates and the highest level of unemployment.¹³

FIGURE 2: Map of DTEE Hardening Areas Compared to Modernization Plans in Detroit (incl. Highland Park & Hamtramck)



Areas for modernization follow broader investment trends that favor Greater Downtown over neighborhoods where more low-income and BIPOC residents live (**Figure 2**). The prioritization on the Lower Eastside aligns with key locations for industrial and municipal customers rather than residential consumers.

¹³ CDC Social Vulnerability Index (SVI), 2018. URL: <https://www.atsdr.cdc.gov/placeandhealth/svi/index.htm>
1

“Communities served by **4.8 kV** are plagued by the highest trouble in the DTE Electric system, yet the very system that causes the increased trouble is also the one that limits their ability to seek solutions.”

- Joy H. Wang, Ph.D., staff at MPSC, Testimony (pp. 86)¹⁴

CONCLUSION

The DTEE rate case, asking for a fifth increase in the last 7 years, presents an opportunity for the Michigan Public Service Commission, elected officials, and communities to advocate for equitable modernization of the grid while advancing affordable and clean power.

Detroit, a city with demographic majorities of BIPOC communities, faces some of the starkest disparities related to inadequate electric infrastructure and inequitable investment and prioritization. The issue of utility redlining must be addressed at the root - how infrastructure investments are justified, whether equity analysis is required, and how utilities are held accountable.

—
Alex B. Hill is Research Director at We The People MI; **Jackson Koeppel** is an independent consultant working with Soulardarity

¹⁴ *Qualifications and Revised Direct Testimony of Joy H. Wang, Ph.D., Before the Michigan Public Service Commission, State of Michigan (2022)* (statement of Joy H. Wang, public utilities engineer in Electrical Operations Section, MPSC)
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PUBLIC INTEREST

DTE, Consumers win \$231M in approvals despite reliability woes

Updated: Mar. 04, 2024, 10:25 a.m. | Published: Mar. 01, 2024, 3:00 p.m.



Power lines from the Ludington Pumped Storage Plant on Monday, July 10, 2023. The hydroelectric plant and reservoir, built between 1969 and 1973, is owned jointly by Consumers Energy and DTE Energy and operated by Consumers Energy. (Cory Morse | MLive.com) Cory Morse | MLive.com



By [Sheri McWhirter | smcwhirter@mlive.com](#)

LANSING, MI – Utility regulators approved major financial requests from Michigan’s two largest electricity providers, but not without bemoaning service reliability problems residents have complained about for years.

The Michigan Public Service Commission (MPSC) voted on Friday to approve \$139.5 million for DTE in cost recovery for the 2021 fiscal year, and a \$92 million rate increase for Consumers. Commissioners also voted to require both DTE Energy and Consumers Energy to provide the state more data about electric power reliability of their grid systems.



Cost recovery is a process for utilities to be reimbursed for fuel and related transportation costs not covered by customers’ regular capacity bills. State law prevents markup on these expenses.

The MPSC denied some of DTE’s submitted costs, like those from a 2019 overhaul at the Ludington Pumped Storage Plant on Lake Michigan. However, state analysts found the utility’s costs associated with the NEXUS natural gas pipeline to transport fuel to its power plants was reasonable and prudent.

DTE officials said the decision by regulators confirms the company’s actual fuel and transportation expenses, and that customers won’t see an increase to bills because of the decision.

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Commissioners made that decision without discussion. However, they each made lengthy comments about their vote to approve a \$92 million electric rate increase for Consumers Energy.

State officials said a typical residential customer using 500 kilowatt-hours per month will see an increase of \$1.53, or less than 2%, on their monthly bill.

The three-member panel said Consumers must better demonstrate how more money from ratepayers will improve grid reliability and reduce power outages.

Commissioner Alessandra Carreon said doubt can be cast on the justification for Consumers' cost recovery because the company "cannot always or does not always demonstrate how each dollar ... spent towards restoration actually translates into shorter outages."



Michigan Public Service Commission (MPSC) commissioner Alessandra Carreon in Lansing on Friday, Dec. 1, 2023. (Garret Ellison | MLive) Garret Ellison | MLive

The March 1 approvals follow years of complaints from Michigan residents who experience frequent power outages that last longer than most other states, statistics show. Metrics also show many Michiganders endure multiple outages in a year.

The state agency has an audit underway for both storm response and grid reliability for both DTE and Consumers Energy. Regulators are even considering tying utility earnings to grid reliability in a "straw proposal."

On Friday, MPSC Chairperson Dan Scripps said the new approved electricity rate for Consumers Energy should provide the funding needed to reduce the frequency and duration of power outages. However, he balked at the way the company's officer compensation incentives are calculated.

Scripps criticized how only 5% of the incentive pay formula for officers at Consumers Energy was connected to reliability performance, while 70% was linked to the company's financial performance.

"When meeting financial metrics counts for 16 times as much as meeting reliability metrics, something is clearly out of whack," Scripps said.

Consumers spokesperson Brian Wheeler said the MPSC's rate approval is the first step on the company's reliability roadmap to fewer and shorter outages.

"The company's investments to add technology, bury power lines and clear trees, are essential to improving reliability for customers. We're acutely aware of the impacts on customers' bills, which is why we're balancing these upgrades by trimming costs and working more than ever to connect customers with cost-saving programs," Wheeler said.

Initially, Consumers requested a \$216 million rate increase though it later reduced the amount to \$170.8 million.



Warning tape that reads "Danger - live wire - keep away" surrounds a fallen limb and power line at the corner of Brockman Blvd. and Copley Ave. in Ann Arbor on Thursday, Feb. 23, 2023. Jacob Hamilton | MLive.com

Environmental and consumer advocacy experts said state regulators cutting by more than half the company's initial rate increase request is an overall win for ratepayers.

Amy Bandyk, executive director at Citizens Utility Board of Michigan, said the MPSC's decision comes at a time when spending discipline is badly needed for Consumers Energy. The nonprofit intervened in the rate case.

"The MPSC rebuked Consumers Energy on its proposed rate hike that would have made electric bills even more unaffordable when Consumers Energy customers already pay some of the highest rates in the country," she said.

n Ahead of Elections Analyst Predicts He

Bandyk encouraged regulators to remain skeptical of the company's spending plans on the distribution grid without showing it is pursuing the most cost-effective strategies.

Environmental watchdog Charlotte Jameson, chief policy officer for nonprofit Michigan Environmental Council, said the MPSC decision is a decent outcome but room for improvement remains.

"This case is yet another example of how our current rate case system fails Michiganders in terms of affordability. It is a continuation of the cycle of utilities coming in every year for rate increases with very little to show in terms of improved performance," Jameson said.

"The commission is hamstrung by the current rate case statute and tries to limit rate increases to some extent. But frankly, that is a piecemeal and inadequate response."

She argued Michigan lawmakers should consider changing the way it's done to a performance-based ratemaking system.

Also intervening in the case was Michigan Attorney General Dana Nessel, who argued that in many ways the rate increase request by Consumers Energy was excessive.

"My department will continue to advocate for Michigan consumers at every opportunity, and we will intervene to defend ratepayers as appropriate based on our careful study of these corporate filings and consultation with industry experts," Nessel said in a statement.

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[Regulators tell Michigan utilities to align with new energy laws](#)

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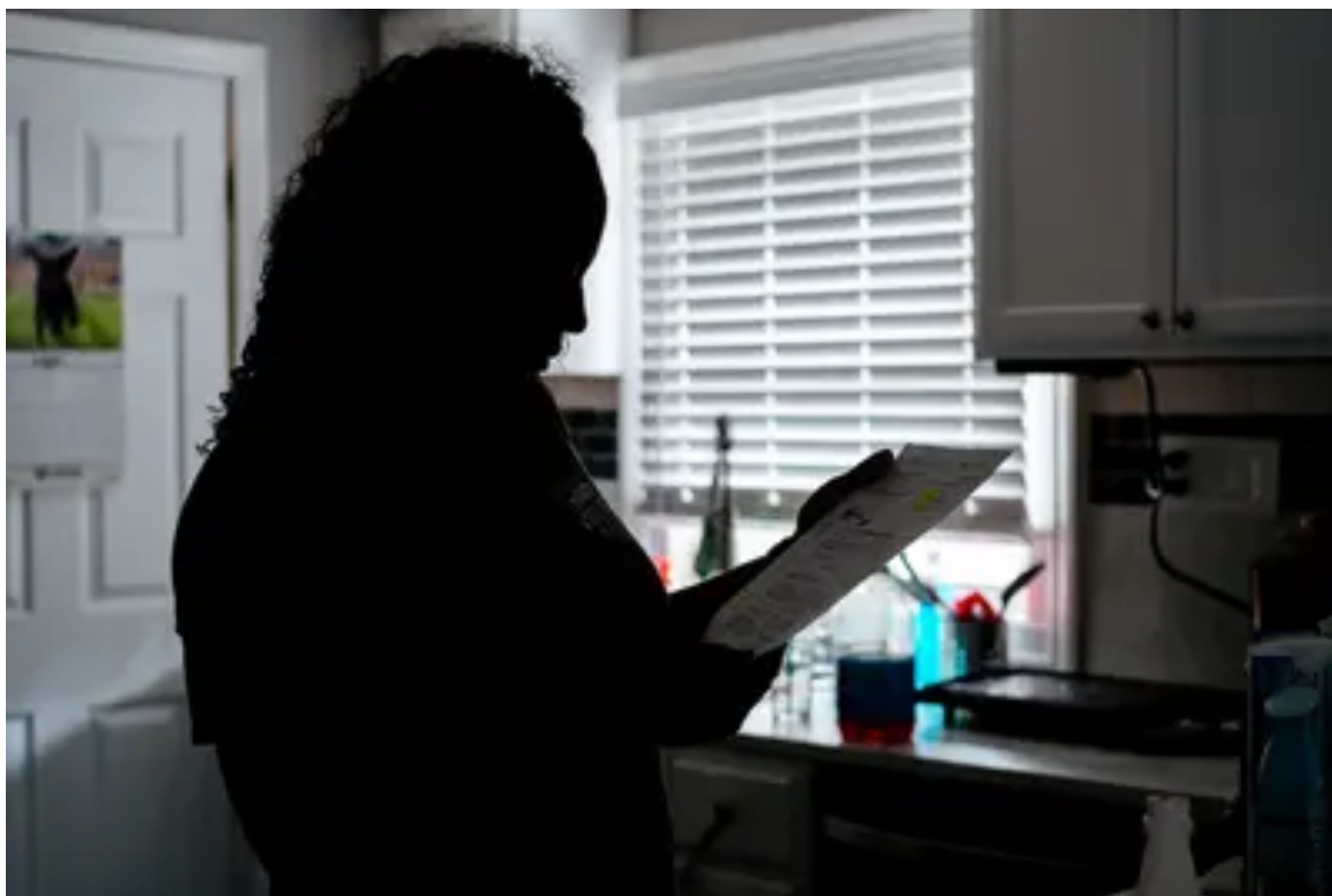
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Around the Web

She Didn't Know She Still Owed Money to Her Utility. Then 25% of Her Paycheck Was Gone.

After the state's largest utility sold consumer debt, thousands of Detroiters faced default judgments and garnished wages. The utility only reaped pennies on the dollar.

Aug. 19, 2022, 5 a.m. EDT



Kristal Dailey looks at a court document from Jefferson Capital Systems' case against her. Nick Hagen for ProPublica

This article was produced for ProPublica's Local Reporting Network in

partnership with [Outlier Media](#). [Sign up for Dispatches](#) to get stories like this one as soon as they are published.

Last November, Kristal Dailey looked at her weekly paycheck and realized about \$150 was missing, a quarter of her take-home earnings from a factory just outside Detroit, where she makes just over \$18 an hour.

"I'm like, 'What the heck is this from?'" she said.

Dailey immediately reached out to her company's human resources department. That's when embarrassment and then anger replaced her initial shock.

Her check, she learned, was being garnished over a \$1,500 debt that was at least five years old. The money was being taken by a collection company she'd never heard of, after a court hearing she hadn't attended. The garnishment went on for more than eight weeks; no matter how much she worked, 25% of her wages were garnished.

"It was terrible," she said. "I just had a baby, just got back to work. For them to start taking \$150, \$160 out was drastic to me."

The original source of the debt was quite familiar to her: DTE Energy, the Detroit area's largest utility company.

The company had quietly sold off Dailey's debt in 2017, along with that of more than 290,000 other residential customers and nearly 14,000 commercial accounts, in a little-noticed financial maneuver, Outlier Media and ProPublica found.

The sale brought DTE just pennies for each dollar owed: \$4.8 million in exchange for the right to pursue more than \$282 million in debt. But for low-income customers whose debt was sold, it was a consequential event, thrusting them into the hands of a debt collector that aggressively sues people. Under Michigan law, these cases can result in creditors garnishing

up to a quarter of a person's wages, as well as refunds from their state income tax returns.

DTE officials declined to be interviewed and did not answer a list of detailed questions sent by reporters. Spokesperson Brynn Guster said in an email that the company is "focused on managing affordability for our customers" and that selling closed customer accounts lowers the burden on other customers.

The company's debt sale practices are unusual. Outlier and ProPublica surveyed the 11 other investor-owned electric utilities that each serve at least 400,000 customers in the Great Lakes states of Illinois, Indiana, Michigan, Minnesota, Ohio and Wisconsin. All of them, including Consumers Energy, Michigan's second largest utility company, said they do not sell debt. Five of the utilities also said they do not directly sue their customers over debt. The ones that do said they do so only on rare occasions.

Regulators in Michigan have paid little attention to DTE's debt practices, even though utilities must receive the state's approval for many other financial decisions. Outlier Media and ProPublica used a combination of publicly available disclosures, local court records and interviews with DTE customers to understand the scope of DTE's debt sales.

These new findings follow a March investigative report by the news organizations that examined how [DTE shut off customers' power for nonpayment](#) during the pandemic. DTE's disconnection rate outpaced all other Michigan utilities owned by private investors and regulated by the state, according to this first-of-its-kind analysis.

Matt Helms, a spokesperson for the Michigan Public Service Commission, the state agency that regulates utilities and approves rate increases, said the commission is prohibited by state law from making management decisions for utilities, such as how they handle debt.

"Given statutory limitations, our focus is on ways to help customers from falling behind in the first place, avoiding situations where unpaid bills may end up in collections," Helms said in an email.

U.S. Rep. [Rashida Tlaib](#), who represents part of Detroit, has advocated for financial assistance that would help low-income people pay off utility debt. Informed of the reporters' findings on DTE, she responded in an email: "Utility companies should not be in the business of selling consumer debt to debt collectors."

DTE, which serves Detroit and nearby areas where large numbers of low-income customers [struggle to afford utilities](#), did not reveal to the regulatory commission which company or companies were buying its debt — only that the debt had been sold. Through a search of court records, reporters identified Jefferson Capital Systems, a Minnesota-based company that buys all kinds of consumer debt, as the purchaser of at least some of it. ProPublica and Outlier made numerous attempts to contact Jefferson, which is owned by a [private equity firm](#), but the company did not respond.

Collection companies that aggressively use the courts rely heavily on the fact that many people do not show up for their initial court hearings or show up without a lawyer to argue the facts of the case. Creditors then win the case swiftly through a default judgment and, in Michigan, this allows them to garnish wages and state income tax refunds.

Experts familiar with these types of legal cases said some people ignore legal notices because they don't recall a debt from years before or don't recognize the name of the debt collection company.

For these collection companies, volume is important, according to attorneys and researchers familiar with debt collection. The more lawsuits the companies file, the more default judgments they are likely to get, and the better their chance to collect via wage garnishments. Even while shut-offs for nonpayment of bills were briefly paused in Michigan in 2020, Jefferson

Capital's lawsuits didn't stop.

It "happens every day. Happens hundreds of times a day," said Charissa Potts, a Michigan bankruptcy lawyer who worked briefly for a third-party debt collector. "That's the basis of third-party collection. That's the business model."

In Detroit's 36th District Court alone, the state's largest, Jefferson Capital filed more than 1,000 cases related to old DTE debt in the first six months of the pandemic, including the suit against Dailey that June.

Years before, she had been shut off by DTE. She then moved in with her partner, and he put the utilities in his name, though she still helps pay that bill. When she was sued in 2020, Dailey was pregnant and working at an industrial-pump-making factory, where her job was considered exempt from the state's stay-at-home order.

Court records say Dailey was notified in person of the lawsuit by a process server, but she disputes that she was ever informed. After the default judgment against her, she eventually negotiated a payment plan with Jefferson Capital that suspended the garnishment and reduced her monthly payments slightly. But that was not enough to make up for the months where 25% of her paycheck was gone. Day care costs allowed for very little room in her budget, and she fell behind on her car payment.

"It threw me so far behind on bills, I'm still trying to play catch-up," she said. "Even now I can't pay the amount I'm supposed to pay."

An Unusual Tactic

DTE handles customers' debt in a variety of ways, working with them on payment plans or pointing them toward financial assistance opportunities. It routinely outsources debt collection to private companies, which is not unusual for a large utility. In general, those collection companies call and mail customers and then keep a portion of what they collect but return most of the proceeds to the company that hired them.

Unlike many of its peers, DTE uses yet another tactic, one that can lead to a court judgment: selling uncollected old debt to third-party debt collectors. In a statement, Guster said the majority of the debt in the sale that affected Kristal Dailey was at least two years old. Guster also said DTE only sells debt from "closed" accounts, meaning after a customer is shut off or moves away from the service area.

Although most of DTE's debt sale information is private, reporters found a few details in financial disclosures the utility filed with the Michigan Public Service Commission. Those records show that DTE has sold debt at least three times in the past 15 years.

Soulardarity, an energy justice group in Highland Park, a city surrounded on all sides by Detroit, has begun to push back at the commission, calling

attention to the toll debt sales take on Detroit-area residents.

"It feels like there's this long cobblestone pathway of financial hell that they are exacerbating and encouraging the existence of," Rafael Mojica, program director for Soulardarity, said of the commission. "We find it unacceptable, and MPSC needs to find it just as unacceptable."

Helms, the commission spokesperson, said in an email that the question of whether utilities should use debt sales is something the state legislature would have to address. In an interview, Dan Scripps, chair of the Michigan Public Service Commission, said the agency's focus is keeping customers out of debt in the first place and that sales are "fairly rare." But while the sales may be rare, they have included the debts of hundreds of thousands of ratepayers throughout the Detroit area.

Reporters searched thousands of pages of utility commission filings and found mention of three DTE debt sales, in 2008, 2014 and 2017. Jefferson Capital is not mentioned in those records. But Outlier and ProPublica were able to verify the sale of some DTE debt to Jefferson Capital, one of the largest collection firms of its kind, through an examination of court data from Detroit's 36th District Court.

In response to a request for debt lawsuits brought by DTE or Jefferson Capital on behalf of DTE, the 36th District Court provided records showing Jefferson Capital filed more than 3,100 cases between January 2019 and April 2022. That number does not include cases where DTE isn't named in the court's electronic records. Reporters were able to find additional cases like these by observing virtual court hearings.

By contrast, 36th District Court records did not show any cases where DTE directly sued its customers over debt during those three years. Guster, DTE's spokesperson, said DTE does not directly sue current or former customers over debt.

The lack of uniform court data makes analysis of Jefferson Capital's lawsuits throughout the entire DTE service area impossible, according to a spokesperson for Michigan Courts.

Using the courts to target large numbers of people is typical in the debt buying industry, said Jeff Reichman, a data scientist with January Advisors and a collaborator of the Debt Collection Lab, a Princeton University project that tracks and visualizes debt collection lawsuit data. "These debt buyers have a legal operation across the country where they can file cases like a machine," he said. Reichman said the volume of cases means judges have less time to spend examining them for flaws, such as debt that is too old to collect or debt that is owed by another person.

To show regulators how debt sales affect customers sued by Jefferson Capital, Soulardarity asked one of its volunteers, Stephanie Johnson, to testify at a utility commission hearing in January where DTE was seeking a rate increase that would bring in an additional \$388 million in annual revenue from ratepayers.

Johnson racked up her debt to DTE over more than a decade beginning in the early 2000s. She said she was raising a family and then went back to college to finish her degree. Johnson had a payment plan that kept her utilities on as long as she paid DTE a fixed amount each month, but the payments weren't enough to keep her from building up a big debt.

In 2016, when she was no longer able to keep up with her bill, she said, she fell off her payment plan, and her entire balance of more than \$5,000 came due, as is typical when such payment plans fall apart. When she couldn't pay, she said, she closed her account and her husband took over the utility bill.

A lawsuit from Jefferson Capital, which had purchased her old debt, followed four years later. Johnson suddenly had to scramble to find money.

Following a default judgment, she said, Jefferson told her it would accept a lump sum payment of \$3,600 to satisfy the debt. She borrowed the money from her mother.

Johnson, who works at a social service agency, is incredulous DTE sold her debt for a fraction of its face value so that Jefferson Capital could make a profit.

"When I really reflect on it, all DTE had to do was reach out to me and say, 'If you can pay this much?'" she said. "Instead they sever the relationship with you, and then they sell your debt."

She added: "You're just trying to keep your life going. We are so dependent on electricity."

All utilities have some portion of debt they determine is unrecoverable and write off their books. Utilities can then ask regulators to allow them to increase rates to cover these costs. The unpaid debt doesn't make or break DTE's bottom line. The amount that remains unrecovered is equivalent to less than 1% of the company's average annual revenue, according to testimony on behalf of Michigan's attorney general before the MPSC.

Consumers Energy, which serves about 1.8 million customers in Michigan, said it stopped taking customers to court over debt in 2019. The reason, a company spokesperson said, was the company "thought it was in the best interest of our customers."

A spokesperson for ComEd, which delivers electricity across Northern Illinois, including Chicago, said the utility rarely takes residential customers to court over debt and can recover more money by continuing to collect on the debt than it would make in a one-time debt sale. Customers' experience is another factor.

"ComEd wants all of our current and former customers to be treated fairly

and with respect," Tom Dominguez, communications manager for ComEd, said in an email. "By keeping this dialog open, we also have a chance to find one of our many bill-assistance options that can help these customers remain in service in the longer term."

Dragged Into Court

Iris Foster-Ray joined her Zoom court hearing in May from her living room, alone, facing off against Jefferson Capital.

She ended up there after she lost control of her DTE debt during a period where one of her twin daughters was ill and her family was struggling with high medical bills. She said her daughter, who is now 20, has a rare circulatory disease, one that gives her heart palpitations and makes her prone to fainting. It took years of medical evaluation to properly diagnose her and, to help treat her condition, she needs to follow an expensive special diet.

Foster-Ray planned to explain all this to the judge, as well as how these financial stresses were worsened by Jefferson's garnishment of \$600 per month, which had begun in January. Foster-Ray, who works in billing at a local children's hospital, was falling behind on her car payments, and her husband needed to pick up a second job.

Judge Ronald Giles sent her to a digital breakout room with an attorney representing Jefferson Capital. When they returned a few minutes later, they had not reached an agreement.

"I can't afford that amount they're taking out of my check," Foster-Ray told the judge. "I have a disabled child, and I have a lot of medical —"

Giles cut her off.

"Hold on, hold on. I understand, but none of that deals with the issue," he said.

That's when reality set in. It was too late for Foster-Ray to defend herself against the original judgment, which had come at the initial hearing in the case.

Foster-Ray hadn't been there that day. After she found the notice of the lawsuit on the door of her home in Detroit's West Side, she didn't know what to do. She'd never heard of Jefferson Capital and didn't think it would be collecting on such old debt. Even after calling the company, she said, she still thought it might be a scam. So she ignored Jefferson's notice.

With Foster-Ray absent from that initial hearing, the court had ruled in favor of Jefferson Capital by default. Foster-Ray spent half a day at the courthouse to file an objection to the garnishment. She thought she'd have the chance to explain her circumstances to a judge.

But the May hearing had one focus and it wasn't whether she had to pay Jefferson Capital.

The court had already decided that; the only question on that day was how much she was going to pay each month.

Foster-Ray's paperwork, redacted by ProPublica, showing the lien placed on her home by Jefferson Capital Nick Hagen for ProPublica

An official from Detroit's 36th District Court, who asked not to be named because they did not have permission to speak on this issue, said Foster-Ray's experience is not unique.

The official understands how some people conclude that they don't need to show up in court but emphasized how important it is to be there. "If you get something in the mail from Jefferson Capital, the first thought in your mind is 'I've never done business with Jefferson Capital, why am I going to respond to this?'" the official said. "I think that's how some of our litigants get into a

little bit of confusion."

There are few protections for people who get sued by debt collectors. No state requires legal representation for defendants in private consumer lawsuits, leaving many people to fend for themselves. The National Consumer Law Center rates Michigan [worse than all but four other states](#), giving it an F for failing to protect its residents in debt cases because it allows wide latitude for creditors to seize Michiganders' property and income.

"Listen, the system sucks," said Sergei Lemberg, the founder of Lemberg Law, a consumer law firm representing debtors in 29 states. "It's the haves against the have nots."

Collectors are "hiring people who know what they're doing, against ordinary people. And they're prosecuting people in the courts, and people are helpless," he said.

Kristal Dailey, who also filed an objection to her garnishment, certainly felt helpless. At a garnishment hearing, she negotiated a payment plan, but it still left her overburdened. She quickly fell behind in payments, and Jefferson Capital went back to court to garnish her wages again. She is looking for part-time work on top of her factory job to pay off the \$800 she still owes.

"You don't have options," Dailey said. "You have DTE or you have nothing, and it's unaffordable, but you don't have a choice."

In Foster-Ray's case, she and Jefferson Capital agreed to a payment plan at her court hearing: \$150 a month. If she misses a payment, the company can resume garnishing her wages.

Foster-Ray accepts responsibility for falling behind on her DTE bills, but said she wishes the utility hadn't sold her debt to a third party.

"I could have done a little bit more at the time," she said of not paying off her

original debt after her utilities were shut off in 2017. "I did push it back to the back burner because my child was sick."

Jefferson Capital recently placed a lien on her house that will remain there until her debt is paid off. In addition to the money she pays Jefferson Capital every month, she must also still cover the cost of DTE's service.

Her family's July bill for gas and electricity — paid through her husband's account since hers was closed — came to more than \$500. She's considering filing for bankruptcy.

"It's like I'm going to work just to pay them," she said.

Correction

Aug. 19, 2022: *This story has been updated to correct details in Stephanie Johnson's experiences with DTE debt. She did not get shut off by DTE in 2016 but did close her account. She also faced a default judgment with Jefferson Capital before working out a payment to satisfy her debt.*



Recognition of and response to energy poverty in the United States

Dominic J. Bednar and Tony G. Reames

A household is energy poor when they cannot meet energy needs. Despite its prevalence, the US has not formally recognized energy poverty as a problem distinct from general poverty at the federal level, which limits effective responses. In this Review, we examine the measurement and evaluative metrics used by the two federally-funded energy programs focused on reducing high energy bills to understand how program eligibility requirements and congressional funding appropriations have shaped the national understanding and implementation of energy poverty assistance. We find that current measurement and evaluative metrics hinge on the distribution of government resources and the number of vulnerable households assisted, rather than improving household well-being and reducing overall energy poverty. We suggest that comparisons to formal food insecurity and fuel poverty recognition and national responses in the US and UK, respectively, can help inform the development of more comprehensive US responses to energy poverty going forward.

Stark disparities exist in US energy burdens, the percentage of household income spent on energy bills. Urban and rural low-income households (defined as 80% of area median income or 150% federal poverty level) spend roughly three times as much of their income on energy cost as compared to non-low-income households (7.2% and 9% versus 2.3% and 3.1%, respectively)^{1,2}. Moreover, low-income, African American, Latinx, multifamily and renter households are disproportionately impacted by high energy burdens¹. Out of a total of 118.2 million US households, in 2015, the US Energy Information Administration (EIA) estimated that 17 million households received an energy disconnect/delivery stop notice and 25 million households had to forgo food and medicine to pay energy bills³. These household experiences have been described as indicators of energy insecurity or energy poverty—the inability of a household to meet their energy needs⁴. Yet, for the United States Government, energy insecurity and energy poverty are nebulous terms that do not exist in any statutory capacity. In other words, the federal government has not formally recognized energy poverty as a distinct problem.

In the absence of federal energy poverty recognition, states have implemented low-income energy assistance programs. Consequently, 51% of all funding to address high energy burdens is from utility ratepayer funded bill and energy efficiency assistance¹. Despite the absence of federal statutes to characterize, measure and evaluate the landscape of and responses to energy poverty, the essence of this phenomenon has generally been recognized in the US as evidenced by two federally-funded energy assistance programs: the Low Income Home Energy Assistance Program (LIHEAP) and the Weatherization Assistance Program (WAP). LIHEAP and WAP are administered by two different federal agencies, the Department of Health and Human Services (DHHS) and the Department of Energy (DOE), respectively. These programs were created to combat rising energy costs and promote household energy sufficiency in response to the 1973 oil crisis⁵. However, after nearly fifty years of federal energy assistance, one in three US households (37 million), still experience energy poverty³.

While the UK and US have had similar responses to energy poverty reduction, one key area of divergence lies in their formal

recognition. Notably, the UK's fuel poverty strategy formally recognizes households as fuel poor when incomes are lower than average and fuel costs are higher than average⁶. Despite a lack of data supporting precipitous reductions in fuel poverty, the UK is armed with pivotal information to aid a more rapid and adaptive response to fuel poverty exacerbated by the climate crisis⁷. Moreover, the requirements to systematically advance household energy efficiency by specific dates signals a united and national priority for overall household wellness and access achieved through the multiple benefits of energy efficiency⁸. Unlike the devolved UK nations⁸, the United States lacks federal energy poverty recognition and strategy that encompasses definitions, reduction targets/objectives and periodic evaluation.

In this Review, we suggest that the absence of formal energy poverty recognition at the federal level limits a more comprehensive understanding of and effective response to energy poverty as a distinct problem, and not simply a manifestation of more general problems of poverty. To this end, we describe energy poverty as the distinct notion of household energy deprivation that limits social and material necessities for participation in society⁹. We first review federal responses to energy poverty in the US as pseudo recognition. The energy poverty responses deployed by LIHEAP and WAP are used as case studies to describe how program eligibility requirements and congressional funding appropriations shape our understanding and targeting of which households require energy assistance. Then, we examine the performance measurements embedded within evaluative standards that indicate the program's success to demonstrate the misunderstanding of each program's effectiveness in reducing energy poverty. Next, we draw parallels to formal recognition and responses to food insecurity in the US, and to fuel poverty in England, as a way to promote a more expansive understanding of the current and future landscape of energy poverty and pathways to effectively responding in the US. We conclude with recommendations to advance national energy poverty reduction in the US, and in particular encourage the development and reassessment of an expansive energy poverty definition, reduction objectives, integrated strategies, and comprehensive measurement and evaluation.

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US response to energy poverty as pseudo recognition

Notwithstanding recognition short of a formal energy poverty definition, LIHEAP and WAP, alongside state level affordability targets and energy efficiency objectives serve as national responses to the issue. Government action at the intersection of energy and equity has been driven by either geopolitical or economic crises that affect energy prices, rather than by a comprehensive, long-term approach to address disparities in energy affordability. Energy poverty response as pseudo recognition has a nearly fifty-year history in the US beginning with the state of Maine's Office of Economic Opportunity initial recognition of the impact that the 1973 oil crisis had on low-income and elderly households' ability to meet their energy needs. In response, they applied for federal funds to implement 'Project Fuel'. Project Fuel's main focus was to weatherize homes; however, funds were also used for crisis counselling and purchasing fuel in emergency situations. Project Fuel inspired weatherization at the national level with a focus on household weatherization and energy conservation; additionally, funds were allowed for fuel voucher programs. The oil crisis catalysed a series of US government reorganizations and the creation of new energy-related departments and programs, by which weatherization and household energy assistance became responses, or pseudo acknowledgements, of the issue of energy poverty. Figure 1 presents a timeline highlighting relevant policies associated with energy poverty responses, including the economic crisis of the late 2000s, which heightened government attention to low-income energy assistance programs and increased funding appropriations.

LIHEAP, authorized in 1981, provides home energy bill assistance to help subsidize high energy expenditures for low-income households. The WAP, authorized in 1976, is the largest and longest running federally-funded residential energy efficiency program. WAP provides eligible low-income families with the opportunity to permanently reduce onerous energy bills through cost-effective, energy efficiency upgrades. As a requirement, whole-house retrofit approaches are used to ensure the cost-effectiveness of energy efficiency measures. The whole-house approach guides energy efficiency measures by looking at the synergy of the building's envelope, appliances, and heating and cooling systems. Private contractors and in-house employees deliver weatherization services to WAP participating homes each year.

Program eligibility requirements, defined by statute and embedded within the purpose of both LIHEAP and WAP, identify which households are eligible for energy assistance and govern program targeting and implementation. Table 1 presents the LIHEAP and WAP program purpose, eligibility requirements and performance measures. Targeting approaches for WAP and LIHEAP are centred on income eligibility, a high energy burden, and demographic characteristics of a 'vulnerable household'. The statutes define vulnerable households as those with young children below five and elderly members above 65 years old, and individuals with disabilities. Eligibility based on household income maintains energy burden as the dominant metric to understand the prevalence and severity of US energy poverty.

LIHEAP and WAP are administered as block-grants by DHHS and DOE, respectively. Combined, the federal government has spent over US\$134.6 billion on low-income household energy assistance since the late 1970s. LIHEAP is a revenue support system provided to eligible households each year, whereas WAP is often a one-off, non-recurring capital investment in energy efficiency measures. LIHEAP benefits roughly 25 percent of eligible households each year and WAP has weatherized 7 million households; however, nearly 40 million households remain income-eligible for energy efficiency assistance¹⁰. Federal block-grants are provided to states, the District of Columbia, territories and Indian tribal organizations and are implemented at times, alongside utility ratepayer dollars at the household level by local governments or non-profit agencies, most often Community Action Agencies.

Program implementation is also shaped by annual congressional funding appropriations. For WAP, formula allocations for each state are based on three factors: low-income population as a share of the nation's total low-income population expressed as a percentage; climatic conditions obtained through heating and cooling degree days for each state; and, residential energy expenditures by low-income households in each state¹¹. For LIHEAP, the funding formula is a bit more complicated and was updated in 1984^{12,13}. Appropriations are released each year contingent on the formula and congressional Continuing Appropriation Resolutions. The previous formula of 1981 determined allocation percentages based on antiquated data, political compromise and accommodation¹². The 1984 'new' formula represents a percentage of US low-income energy expenditure by state. To capture state level low-income energy expenditure, the following values are used for household-level calculations: total residential energy consumed as measured by total British Thermal Units (Btu); temperature variation as 30-year average heating and cooling degree days; heating and cooling consumption for total US and low-income households; and average fuel price per fuel source.

Appropriations for these two programs have fluctuated over time, each receiving large boosts during the recession-era American Recovery and Reinvestment Act of 2009. It is important to note the historical disparity in their funding appropriations as shown in Fig. 2. LIHEAP funding averages nearly US\$3 billion annually since its inception. WAP funding pales in comparison to LIHEAP appropriations, averaging nearly US\$0.4 billion annually¹⁴. Comparatively, LIHEAP allows states to transfer up to 25% of its funds to WAP, making LIHEAP one of the largest additional potential funding sources for WAP. Even with greater funding, a majority of income-eligible households (84%) do not receive LIHEAP assistance¹⁰. Naturally, the immediate need of bill-assistance is greater than the speed at which households can be weatherized, warranting greater funds to LIHEAP. Nevertheless, the persistence of greater appropriations to LIHEAP over WAP appears to reflect a policy approach based on a notion that energy poverty is a temporary misfortune to be remedied primarily by some form of debt recovery, despite evidence demonstrating WAP as an effective and sustainable solution towards household energy affordability with multiple benefits¹⁵, including those to public health.

States have regulatory authority over LIHEAP and WAP implementation, and there are trends toward recognizing energy affordability as a policy priority at the state level. For instance, certain states have specific target dates to achieve energy efficiency objectives, such as Connecticut which aims to weatherize 80% of homes by 2030 (Public Act No. 11–80). Other states and municipalities have energy affordability goals. For example, the Governor of New York created an energy affordability policy in 2016 with a six percent energy burden goal and Portland, Oregon has a 10-year plan to reduce energy burdens in Oregon affordable housing. Moreover, several state-level energy regulatory requirements ensure low-income energy assistance is provided in the form of energy efficiency and bill payment assistance to achieve energy affordability. State energy efficiency resource standards by law require utilities to pursue energy efficiency as a cost-effective energy resource¹⁶. Although eligibility requirements vary, utility ratepayer-funded programs often complement LIHEAP assistance and are funded through charges assessed on all or some commercial, industrial and residential customers. The assessed charges are often referred to as public goods surcharges, system benefits charges, public benefits, universal service fees, universal energy charges, or meter charges. State and local funds administered as supplements to LIHEAP funding garners eligibility for incentives from the federal government, thus increasing available resources to distribute. Additionally, on-bill financing programs are loans made to utility customers to pay for energy efficiency improvements.

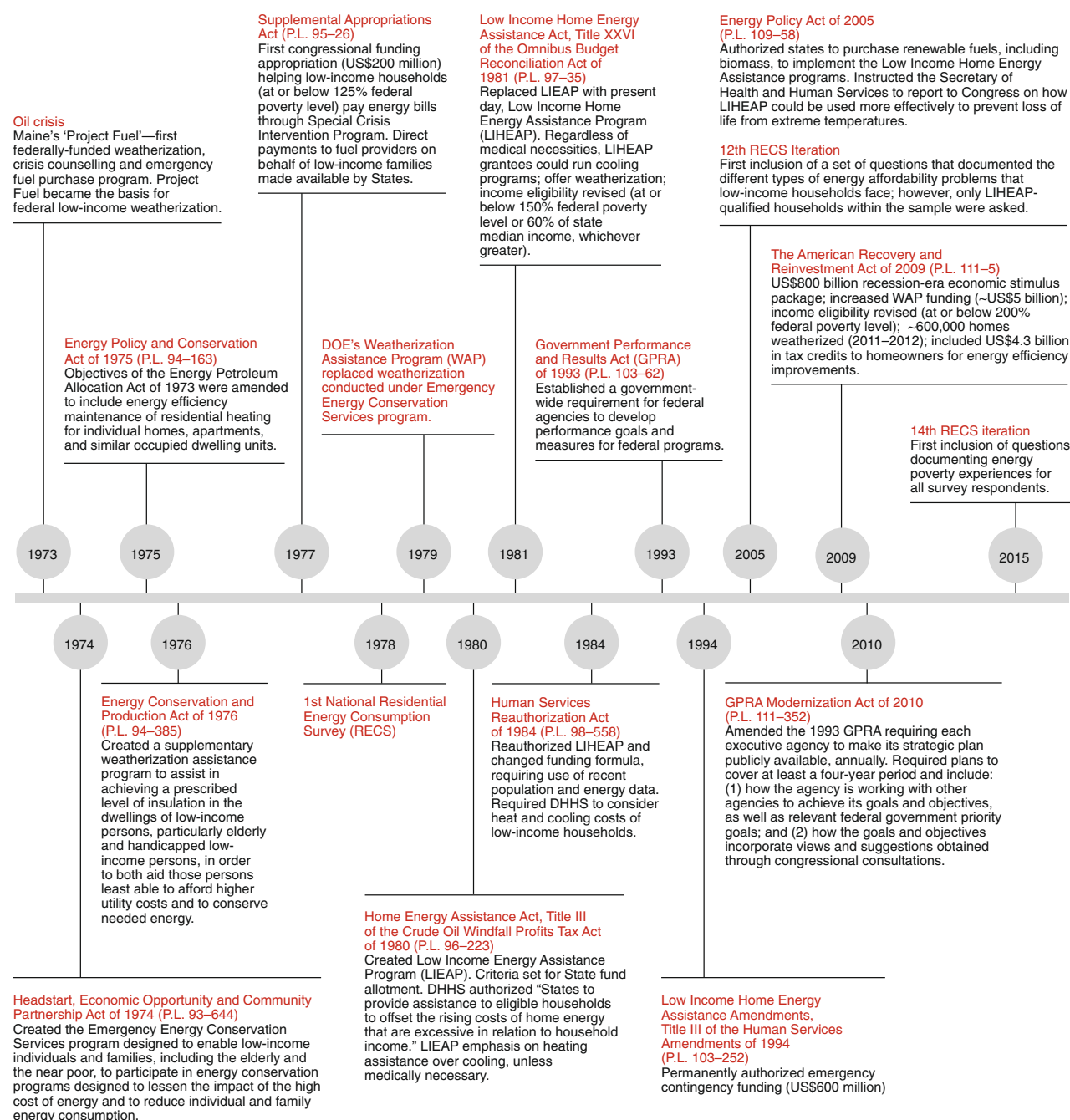


Fig. 1 | Timeline of US energy poverty response-as-recognition. Key developments in Public Law (P.L.) and data acquisition between the years 1973 and 2015.

Evaluation of US responses to energy poverty

Performance measures and program evaluations are the lynchpins of federally funded energy assistance. They inform both the executive branch's and congressional committees' decision making about the programs they oversee¹⁷. The Government Performance and Results Act (GPRA) of 1993 emerged out of the 'frustration' that decision making was hindered by the shortage of good information on the results of federal program efforts¹⁷. Its update, the GPRA Modernization Act of 2010, reinforced key elements for improving the effectiveness and efficiency of government.

This Act emphasized the use of goals and measures to improve outcomes and requires quarterly review of progress achieved towards goals.

Performance goals/objectives are important because they guide performance measures that inform evaluations of program performance. Performance measures aim to provide quantifiable information on the effectiveness of meeting program performance goals/objectives. In other words, they help to evaluate the success of programs. Two organizations, APPRISE, Inc. (Applied Public Policy Research Institute for Study and Evaluation) and Oak Ridge

Table 1 | Comparison of LIHEAP and WAP purpose, eligibility requirements and performance measures

Program	LIHEAP	WAP
Year created	1981	1976
Administering agency	US Department of Health and Human Services, Administration for Children and Families, Office of Community Services, Division of Energy Assistance	US Department of Energy, Office of Energy Efficiency and Renewable Energy, Weatherization and Intergovernmental Programs Office
Agency mission	To enhance the health and well-being of Americans by providing effective health and human services and by fostering medicine, public health and social services	To ensure America's security and prosperity by addressing its energy, environmental and nuclear challenges through transformative science and technology solutions
Purpose	"to assist low-income households, particularly those with the lowest incomes, that pay a high proportion of household income for home energy, primarily in meeting their immediate home energy needs"	"...to increase the energy efficiency of dwellings owned or occupied by low-income persons, reduce their total residential energy expenditures, and improve their health and safety, especially low-income persons who are particularly vulnerable such as the elderly, persons with disabilities, families with children, high residential energy users and households with high energy burden"
Eligibility	Highest value between a household: •being at or below 150% of the federal poverty level (FPL) income guidelines; or •60 percent of the state median income	•200% FPL •Recipient of Supplemental Security Income or Aid to Families with Dependent Children and less than 200% FPL (US DOE, 2017)
Performance measures	Reciprocity targeting index	Number of homes weatherized
	Energy burden measures	
	Benefit target index	
	Burden reduction target index	
	Prevention and restoration measures	
	Service loss prevention	
	Service restoration	

National Lab, are commissioned to serve as performance review committees/workgroups to conduct program evaluations for both LIHEAP and WAP, respectively.

The DHHS annual performance goals/objective focus on targeting LIHEAP heating assistance to vulnerable, low-income households that have the highest energy burdens. However, individuals with disabilities are not included in this assessment of vulnerable households.

The reciprocity targeting index is currently the only evaluative LIHEAP performance measure that quantifies the targeting performance objective and describes the national percentage of eligible households that receive services and have either a young child or senior citizen in the household^{18,19}. In 2014, four new 'developmental' performance measures were approved to quantify LIHEAP's impact on household energy burdens, prevention of energy loss, and restoration of energy services to allow State grantees building capacity for necessary data collection (Table 1).

Although the current LIHEAP performance measures satisfy the statutory requirements for monitoring and reporting, less is known

about the program's effectiveness in reducing the actual problem of energy poverty. The performance measures maintain and emphasize a 'distributive' goal that focuses on inputs—how government resources are distributed—and outputs—the number of vulnerable beneficiaries assisted—rather than impact or outcomes, such as how the program has influenced the lives of all households experiencing energy poverty. According to DHHS, performance measures were not met in some years²⁰, formally signalling program failures to the federal government despite having assisted over 6.3 million households with heating¹⁰, and more recently cooling, costs. The approved performance measures provide useful information from an operational standpoint on whether LIHEAP assistance is working. However, each of these measures lack strategic and long-term understanding of the extent to which LIHEAP reduces negative consequences to the health and well-being of households living in energy poverty. Moreover, no comprehensive national program evaluations have been conducted for LIHEAP despite mandates¹⁷ that call for evaluative information to understand whether and why a program is working well or not.

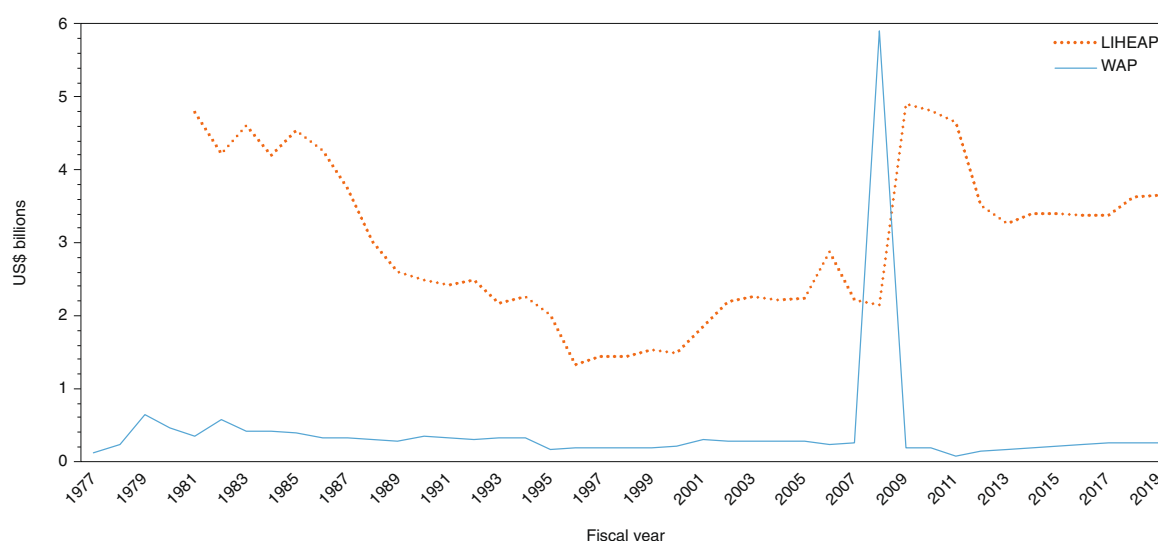


Fig. 2 | Historic LIHEAP and WAP funding appropriations by fiscal year. Values not adjusted for inflation. Shown in current US dollars. Figure data from LIHEAP Clearinghouse (<https://liheapch.acf.hhs.gov/Funding/funding.htm>).

Conversely, WAP has undergone several comprehensive national and local program evaluations since 1993 that assess the operations, cost-effectiveness and non-energy benefits of the implementation and benefits of WAP¹⁵. The peer-reviewed and statistically robust national evaluations have demonstrated that weatherization provides cost-effective energy savings, health and safety benefits, support for job creation, and a stable platform for continued investment in energy efficiency^{15,21}. Specifically, WAP saves households an estimated average US\$283 annually alongside many other non-energy benefits²¹. Non-energy benefits garner US\$2.78 for every US\$1.00 invested into the program, providing more liveable homes, fewer missed days of work and decreased out-of-pocket medical expenses by an average of US\$514 annually²¹. Although these evaluations expand our understanding of the benefits of WAP, the primary performance measure that was used to demonstrate program success, similar to LIHEAP, can be classified as distributive or production-based; specifically, the number of retrofits or low-income homes weatherized. Thus, performance measures have not appropriately assessed the effectiveness of energy efficiency improvements in solving the problem as outlined in the purpose of the established statute.

Although each program seeks to address the symptoms of energy poverty, the legislation creating each program did not formally recognize this problem. Consequently, reduction focused strategies or metrics embedded within a national energy poverty policy to understand the effectiveness of each program's response were not established. Nonetheless, each program has a list of successes, namely, reducing energy costs^{22,23}, improving children's growth and health²⁴, and reducing greenhouse gas emissions^{15,25}. Despite measurable successes, without formal and comprehensive recognition of energy poverty, the effectiveness of current responses continues to be masked by poor performance measures not aligned with national energy poverty reduction.

This review of the LIHEAP and WAP program objectives and relevant policy documents juxtaposed to their fiscal imbalances reveals a dearth of definitions, measures and program evaluations that limit a more accurate characterization of the prevalence, severity and causes of energy poverty experienced in the United States.

US recognition of and response to food insecurity

In contrast to energy poverty, the prevalence and severity of other issues in the US have been recognized and understood more formally,

namely, food insecurity. In 1990, the United States Department of Agriculture (USDA) formally established and endorsed a definition for food insecurity. The need for better monitoring and assessment of the nutritional state in the US led to the enactment of the National Nutrition Monitoring and Related Research (NNMRR) Act of 1990. Embedded within a 10-year comprehensive plan, the Act outlined a task to "recommend a standardized mechanism and instrument(s) for defining and obtaining data on the prevalence of 'food insecurity' or 'food insufficiency' in the United States and methodologies that can be used across the NNMRR program and at State and local levels"²⁶.

To develop the needed measure, the federal interagency working group, the 'Food Security Measurement Project' was founded in 1992 and built on existing research, collaborating with the US Census Bureau and private-sector experts. The group ensured the final measure was appropriate and feasible for standard and consistent use across the country. Annual measurement began in 1995 by administering the food security questionnaire as a supplement to the current population survey. Initial analysis estimated the prevalence rates of food insecurity and produced a scale that measures the severity of deprivation in basic food needs as experienced across various household types. An assessment of the stability and robustness of the measurement model across years, major population groups and household types established the stability of the food security measure²⁷. This type of federal recognition demonstrates the measurement capacity required to respond and reduce energy poverty in the US.

UK recognition of and response to fuel poverty

Rising energy costs during the 1973 oil crisis similarly affected UK households. This section highlights the ways in which the UK has recognized, responded to and evaluated fuel poverty as a way to encourage a more expansive understanding of the current and future landscape of energy poverty in the US.

Recognition. The UK became the first country in the world to formally recognize and strategically respond to fuel poverty. The Warm Homes and Energy Conservation Act of 2000 established a target for ending fuel poverty "as far as reasonably practicable" for all households within 15 years. This recognition prompted a legal commitment to produce a fuel poverty strategy; thus, elevating the urgency of the problem. Formal recognition provided an ambitious

policy objective with outcomes that mattered at the household level. The strategy initially defined a fuel poor household as "...one which needs to spend more than 10% of its income on all fuel use and to heat its home to an adequate standard of warmth"²⁸. Despite insufficient follow-through in practical policies, formal recognition embedded within the UK strategy provided the impetus for understanding the prevalence and severity of fuel poverty through measurement.

The established fuel poverty definition was complemented with an associated metric/measure that helped the UK nations to quantify household energy requirements against the strategy. The 'ten-percent indicator' catalysed national fuel poverty measurement. However, the fixed threshold made this definition hypersensitive to changes in domestic energy costs and made it more difficult to track the impact of implemented response measures that improved energy efficiency²⁹, thus concealing the impact experienced at the household level, rendering the metric invalid.

The critiques of this definition and metric led to the English adoption of the Low Income High Cost (LIHC) metric in the updated 2015 fuel poverty strategy⁶. The LIHC measure identifies fuel-poor households as those where incomes are lower than average and fuel costs are higher than average. This updated metric enabled better targeting and prioritization of English households living in the most severe cases of fuel poverty. However, the devolved nations retain the ten percent indicator. Notwithstanding the capacity of the LIHC metric to identify fuel-poor households, its relative nature is critiqued because it allows households to move in and out of fuel poverty³⁰ and obscures the role energy markets play in creating fuel poverty³¹.

Subsequently, the proposed Low Income Low Energy Efficiency (LILEE) metric aims to broaden and update the current measure to an absolute measure—capturing all low-income households with high costs that live in inefficient homes³⁰. The proposed measure identifies households as fuel poor if they live in property with an energy efficiency rating below band C per the Fuel Poverty Energy Efficiency Rating (FPEER) system and, if after housing costs and energy needs, their income would be below the poverty line³⁰. Based on the government's Standard Assessment Procedure, FPEER assesses the energy performance of domestic properties while accounting for the direct impact policy interventions have on household energy costs³². The current high cost threshold would change to an absolute one while the income threshold remains unchanged per existing LIHC methodology. This metric is better aligned with the statutory fuel poverty targets described in the next two sections, Response and Evaluation. The formal recognition of fuel poverty in the UK as a distinct problem, separate from general poverty, has allowed for an adaptive understanding of the problem's manifestation over time.

Response. Throughout the history of fuel poverty responses in the UK, household energy efficiency improvements were maintained as the primary and most cost-effective vehicle to address the negative impacts on health and well-being associated with living in a cold home. For example, from 2000 to 2013, England's Warm Front Home Energy Efficiency Scheme (WF) lessened the prevalence of fuel poverty whilst cutting greenhouse gas emissions and increasing household annual income³³.

Key fuel poverty policies centre on the implementation of energy efficiency for households. Expressively, this technical conception has been critiqued as potentially damaging, marginalizing other solutions towards income and living cost equality³¹. Even so, the 2014 statutory fuel poverty target for England echoes energy efficiency as the primary method and commits to ensuring that as many fuel poor households as reasonably practicable achieve a minimum FPEER rating by 2030⁶ with interim targets by 2020 and 2025. The 2015 strategy⁶ in England emphasized more effective policy-making and delivery to address the structural problems of fuel poverty and to meet decarbonization goals. To tackle the least energy-efficient private rental properties in England and Wales, the Minimum Energy

Efficiency Standards established a baseline efficiency for new and renewal tenancies based on FPEER. Coordination efforts between relevant health and housing policies with other departments initially hampered the implementation of energy efficiency assistance (WF) to households suffering the most. Since the demise of WF, no government funding is provided for energy efficiency. However, similar to on-bill financing schemes, the Green Deal supports energy efficiency through a pay-as-you-save private loan scheme for household energy efficiency upgrades³³. The Energy Company Obligation (ECO) is an energy efficiency scheme in the UK aimed to tackle fuel poverty. The ECO levies money from each customer as a proportion of their bill, so all income groups contribute payments. The fund is then spent on energy efficiency improvements in people's homes. ECO is meant to be focused primarily on the fuel poor; however, the poor definition of eligibility limits effective targeting.

Evaluation. The annual fuel poverty statistics monitor progress against the 2015 statutory target and track (1) the proportion of households in fuel poverty using the LIHC indicator and (2) their fuel poverty gap, that is the reduction in fuel bill that the average fuel poor household needs in order to not be classified as fuel poor³⁴. These headline statistics are based on data collected by the English Housing Survey, a continuous national survey commissioned by the Ministry of Housing, Communities and Local Government and provides information about the housing circumstances, condition and energy efficiency of English homes. These data are vital elements that support England's Department for Business, Energy & Industrial Strategy (BEIS) to develop, monitor and evaluate the key fuel poverty policies⁶. To measure progress against the 2014 fuel poverty targets, BEIS is legally bound to use FPEER³². The Committee on Fuel Poverty (formally the Fuel Poverty Advisory Group) is a non-departmental public body sponsored by BEIS established to monitor the English Government's progress on the 2015 fuel poverty strategy and to provide independent, expert guidance on meeting milestones and targets^{6,35}. The UK's fuel poverty evaluation approach provides the mechanisms to track policy goals with embedded public oversight to ensure the government is meeting those goals.

Moving Forward

There is an opportunity to explore the benefits demonstrated by UK fuel poverty and US food insecurity recognition, responses and evaluation. Notably, formal recognition of US energy poverty would catalyse rapid energy efficiency investments, develop universal metrics to understand the landscape of US energy poverty and align LIHEAP and WAP statutes with associated health outcome/impact performance measures.

To move towards a more nuanced understanding of and efficient response to energy poverty reduction, we suggest a more inclusive and efficient inquiry to energy poverty engagement that establishes the prevalence and severity of energy poverty experienced across the US, explores its drivers, determines reasonable energy poverty reduction objectives, investigates how existing policy and programs compliment and coordinate innovative solutions to achieve set objectives, evaluates the effectiveness of deployed solutions and assesses how such solutions may be optimized for climate adaptation. Ultimately, we hope that this leads to the establishment of a statutory amendment that tasks the development of an independent inter-agency working group and a national energy poverty strategy including a definition and comprehensive measurement and evaluation of local, state, and national progress towards set reduction objectives in the United States.

The development of an energy poverty strategy, including definition, metrics and solutions must be reflected in the principles of risk assessment. Failing to acknowledge the risk or potential harm that may occur with living in sub-standard housing, or lack of household

energy, should be regarded as a threat to national well-being and potential to rival other nations and spur economic growth. In recognizing the risks to public health vis-à-vis household energy poverty^{4,36}, risk characterization provides a lens that encourages energy poverty problem formulation. Risk characterization accurately describes hazardous situations in a way that reflects the significant concerns of the interested and affected parties³⁷. This decision-relevant description should be understood and accessible to the parties and public officials³⁷. The usefulness of risk characterization and subsequent risk analysis will fail if the perspectives and knowledge of the interested and affected parties are absent^{37,38}. Applying the techniques of risk analysis and characterization are essential in making informed decisions on human health, welfare and the environment as linked to energy poverty.

Problem characterization and solution interventions should employ an energy vulnerability perspective. Energy vulnerability recognizes the multidimensionality of household energy poverty and offers a new lens to characterize the problem spatially and temporally whilst seeking understanding of the dynamics that influence a household's energy poverty risk. Through this lens, energy poverty is recognized as a 'state' within a certain temporal frame and identifies vulnerability as a set of conditions leading to such circumstances in that state³⁹. Thus, energy vulnerability thinking can be seen as probabilistic, highlighting the factors that influence the likelihood of becoming energy poor³⁹. Correspondingly, a consistent, comprehensive definition of energy poverty centred on the notion of energy vulnerability is vital to formally recognize energy poverty and bridge the assessment gap between scholars, policymakers and program managers. Thus, we propose to define US energy poverty as a state where households are challenged by everyday situations in meeting basic energy needs because of an assemblage of socio-economic, technical and environmental-political factors^{4,40,41}. Factors known to be associated with energy poverty include gender, age, housing age, tenure type, energy inefficiency, education, employment, geography, socioeconomic status and race/ethnicity⁴²⁻⁴⁴.

Given the multidimensionality and variation of energy poverty regionally^{1,2,44}, the production of data that characterizes this problem for the US should be intentional in its exploration. Thus, the development of quality indicators and data sets would aid capturing the essence of this problem beyond existing energy affordability measures. A standardized national instrument developed in concert with an independent, interagency working group is critical to understand the landscapes of energy poverty temporally.

Equipped with the capability to measure different dimensions of energy poverty, reasonable reduction-based objectives surface as an opportunity for local development and national coordination. Objectives establish baseline goals through which energy poverty reduction can be assessed and achieved. Formal energy poverty recognition alongside reduction-based objectives and performance measures would better align LIHEAP and WAP as an official energy poverty strategy that encourages longitudinal data collection and innovative solutions.

The separate federal channels for LIHEAP and WAP limit opportunities for coordination, promote redundant administrative and reporting duties for states and local agencies, and maintain incompatible eligibility requirements. We envision a restructuring that collapses the processes and procedures of LIHEAP and WAP under the DOE given their demonstrated measurement and evaluative efforts and WAP's more expansive statutory purpose. Such restructuring would require a good database⁷ and would promote alignment of broader public health⁴ and carbon mitigation goals with interim targets for energy poverty elimination by 2030 and 2050.

Energy efficiency evaluation, measurement and verification are vital in demonstrating the financial benefits of bill assistance and the multiple benefits of energy efficiency⁴⁵. Reduction focused performance measures and program evaluations offer a means to

incorporate existing WAP evaluation components aimed at minimizing environmental and health risks, whilst maximizing energy and cost savings. Periodic evaluation would maintain a record of the effectiveness of deployed responses. Energy poverty and its responses can then be reassessed to understand how the landscape has changed and how the problem of energy poverty has evolved.

Conclusions

We contend that the absence of formal energy poverty recognition at the federal level has limited a more precise response and more inclusive understanding of the prevalence, severity and causes of energy poverty in the US. Issues of energy poverty remain omnipresent across the US despite the presence of local, state and federally funded energy assistance programs for energy burden reduction. Historically, the US has entrenched its assessment and response to energy poverty through national programs based on low household incomes and relative energy burdens, which has constrained the understanding and targeting potential of energy poverty exclusively towards affordability and away from related health outcomes as a result of household inefficiencies.

Congressional funding appropriations showcase the primary response and disproportionate support that LIHEAP historically receives compared to WAP and elucidate the disparity in investments of federal resources aimed at responding to energy poverty, despite LIHEAP's design as a short-term solution. We do not highlight the disparities in congressional funding as a means to bolster support for its discontinuation or disinvestment. Rather, these disparities magnify the need for purposeful performance measures and systematic program evaluations that underpin the process in funding federal energy assistance programs.

Current performance measures and program evaluations hinge on distributive targets—focusing on the number of households assisted. The consequences of distributive focused performance measures are a product of mis-characterizing US energy poverty and a quotient of its evaluation history, and suggest the inadequacies of LIHEAP to holistically ensure the reliability of adequate household energy services alone. Without appropriate performance measures to aid the evaluation of household energy poverty reduction and health improvement, near and far term understandings of energy poverty reduction and responses will remain insufficient.

Moving forward, a statutory amendment is needed that defines energy poverty, promotes its reduction and develops performance measures to more inclusively understand and evaluate the impact of all energy poverty responses. Energy vulnerability thinking can connect the analysis of inequities in vulnerability to household energy poverty. This perspective maintains the significant role data driven evaluation, measurement and verification of outcomes have on minimizing environmental and health risks whilst maximizing energy and cost savings. Energy vulnerability framing in concert with energy^{46,47} and environmental justice⁴⁸ principles amplify the need for adequate access to affordable household energy and the need to recognize its importance as a national policy issue. This reframing prompts a research agenda and policy action to ameliorate US energy poverty.

To solve the multidimensional issues of energy poverty, the US must develop an expansive framework and respond with clarity. Fortunately, there is an opportunity to tackle energy poverty, which is being exacerbated by climate change and unjust energy transitions, by leveraging the history, shortfalls and innovation of formal fuel poverty recognition and responses in the UK. The preponderance of household energy inequities that plague low-income and households of colour will intensify if the realities of energy poverty in the US are not first acknowledged.

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Competing interests

The authors declare no competing interests.

Additional information

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Inexpensive Heating Reduces Winter Mortality
Janjala Chirakijja, Seema Jayachandran, and Pinchuan Ong
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ABSTRACT

This paper examines how the price of home heating affects mortality in the US. Exposure to cold is one reason that mortality peaks in winter, and a higher heating price increases exposure to cold by reducing heating use. It also raises energy bills, which could affect health by decreasing other health-promoting spending. Our empirical approach combines spatial variation in the energy source used for home heating and temporal variation in the national prices of natural gas versus electricity. We find that a lower heating price reduces winter mortality, driven mostly by cardiovascular and respiratory causes.

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1 Introduction

In the US, 17% of households spend more than 10% of their income on home energy. Heating is the largest component of annual home energy consumption, despite being used for only part of the year (RECS 2009).

High heating costs impose a difficult trade-off on households: They have to keep their home uncomfortably cold to save on heating or forgo other spending to afford their high heating bill. How acute this dilemma is depends on how expensive home heating is. Through both a substitution and an income channel, a higher price of heating could be harmful to health. First, using less heating means exposure to lower ambient temperature, which has been linked to cardiovascular, respiratory, and other health problems.¹ Second, if families do not cut back usage one-for-one when the price rises, their energy bills will increase. This can lead to cutbacks in other expenditures that affect health, such as food and health care.

This paper estimates the causal effect of heating prices on mortality in the US. A large literature has documented that mortality peaks in winter and that cold weather is associated with higher mortality. Our contribution is to examine whether high home heating costs exacerbate this pattern of “excess winter mortality.”

Our empirical design uses spatial variation across the US in the energy source used for home heating. Natural gas and electricity are used for heating by 58% and 30% of households, respectively. Importantly, there is considerable geographic variation across counties in whether an area relies on natural gas versus electricity. We combine this spatial variation with temporal variation in the national prices of natural gas and electricity. The ratio of the natural gas to electricity price varied substantially over the 2000 to 2010 study period, most notably due to the boom in shale production of natural gas. We leverage the fact that households in areas that rely more on natural gas for heating experienced a decline in their home heating price as a result of the shale gas boom, relative to households in areas reliant on electricity.

We find that lower heating prices reduce mortality in winter months.² The estimated

¹The main hypothesized mechanisms are changes in blood pressure and blood chemistry which increase the risk of strokes, myocardial infarctions, and pulmonary embolisms, and higher infection risk due to a suppressed immune system (Crawford et al. 2003; Liddell and Morris 2010).

²We define “winter” in this paper as November to March, the coldest months of the year. Analyses of excess winter mortality use December to March in the UK and Europe, where those are the coldest months (Wilkinson et al. 2004). We include November because the average temperature is as low as in March in the US (see Appendix Figure A1). We also show the results using December to March.

effect size implies that the drop in natural gas prices in the late 2000s, induced largely by the boom in shale gas production, averted 11,000 winter deaths per year in the US. We also find that the effect does not just represent short-run hastening of mortality. We show that the effect, which is driven mostly by cardiovascular and respiratory causes, is robust to several checks on the specification.

Our paper contributes to the literature on the effects of cold weather on mortality (Eurowinter Group 1997; Analitis et al. 2008; Deschenes and Moretti 2009), morbidity (Ye et al. 2012), and nutrition (Bhattacharya et al. 2003; Cullen et al. 2004; Beatty et al. 2014). To our knowledge, ours is the first study to estimate the causal effect of heating prices — a plausibly important and policy-relevant mediating factor — on mortality or, more generally, on health. Previous work has found that the winter spike in mortality is stronger for people living in older housing, which tends to be poorly insulated, which is suggestive but not dispositive that indoor temperature is a mediating factor (Wilkinson et al. 2007). The studies closest to ours examine how home weatherization affects health; some studies report reductions in morbidity, and others find null results (Critchley et al. 2007; El Ansari and El-Silimy 2008; Green and Gilbertson 2008; Howden-Chapman et al. 2007). Most of these studies analyze small samples and thus lack statistical power to examine mortality or other objective health outcomes. Another related literature documents a positive association between heating subsidies for low-income families and health, usually without isolating a causal relationship (Frank et al. 2006; Grey et al. 2017). An exception is Crossley and Zilio (2018) who use a UK program’s age-eligibility rule to study the effects of unconditional cash transfers for the elderly labeled as “winter fuel payments”; the payments reduce one of the two biomarkers for infection examined.

Our paper also contributes to the literature on the consequences of shale gas production, specifically on its health effects due to lower energy prices. Previous work in economics has studied local economic effects of shale gas production on job creation and wages (Feyrer et al. 2017; Jacobsen 2019), fertility (Kearney and Wilson 2018), and crime (DeLeire et al. 2014; Bartik et al. forthcoming). Shale gas also affects health through channels besides energy prices. It often displaces coal in electricity generation, lowering pollution emissions (Cullen and Mansur 2017; Fell and Kaffine 2018; Holladay and LaRiviere 2017; Knittel et al. 2015; Linn and Muehlenbachs 2018). There are also potentially large local health costs due to chemical contamination of the water supply (Jackson et al. 2014; Groundwater

Protection Council 2009; Muehlenbachs et al. 2015). Several recent papers find a link between fracking and poor birth outcomes (Casey et al. 2016; Currie et al. 2017; Hill 2018). The health harm from the toxic chemicals used is likely much larger per person affected than the health benefits from lower energy prices; however, lower energy prices affect a much larger population. Thus, the net health effect of fracking aggregated for the whole US population is ambiguous. Finally, our empirical strategy is similar to that of Myers (forthcoming) who compares households that use heating oil or natural gas in Massachusetts to study whether home energy costs are capitalized into home values.

2 Empirical strategy

We estimate the effect of heating prices on mortality. As a proxy for the heating price that an individual faces, we combine information on whether her locality uses natural gas for heating and the national prices of natural gas and electricity. This approach enables us to control for average differences across localities and time.

2.1 Estimating equations

We estimate the following equation via ordinary least squares regression to quantify the impacts of the price of heating on mortality:

$$\log(m_{jt}) = \alpha + \beta \text{ShareGas}_j \times \log(\text{RelPrice}_t) + \gamma_j + \tau_t + \theta Z_j \times \log(\text{RelPrice}_t) + \delta X_{jt} + \epsilon_{jt} \quad (1)$$

Each observation is a county-month. The outcome $\log(m_{jt})$ is the log of age-adjusted mortality in county j in month t . The key regressor is the interaction of ShareGas_j — the proportion of households in the area that used natural gas for heating in the base year of 2000 — and $\log(\text{RelPrice}_t)$. RelPrice is the ratio of the national price of gas to electricity. When natural gas prices are higher (high RelPrice), areas with high ShareGas face relatively higher heating prices. The hypothesis is that $\beta > 0$: A higher heating price increases mortality. County fixed effects, γ , and month-year fixed effects, τ , absorb the main effects of ShareGas and $\log(\text{RelPrice})$. Throughout, we cluster standard errors by state to allow for serial correlation, as well as spatial correlation among counties in a state.

We include several control variables in our main specification. Because the study period spans the housing market boom and collapse and the Great Recession, we control for a housing price index, the unemployment rate, and the manufacturing share of local em-

ployment income. The vector X also includes air pollutants linked to mortality. We also control for area characteristics Z , specifically pre-period log median income and the share of the population over age 70, interacted with $\log(RelPrice)$; these control variables help safeguard against a spurious correlation from the Great Recession (or another phenomenon with a similar temporal pattern as $\log(RelPrice)$) having a differential impact on mortality across socioeconomic or demographic groups (Hoynes et al. 2012).

For the difference-in-differences estimation, we restrict the data to only winter months (when possible), when energy use is mostly for heating and most of the year’s heating is consumed. We also estimate a triple difference model that uses the non-winter months as an additional comparison group, testing the prediction that the price of heating affects mortality more in winter than in other, warmer months.

Some winters or particular months in winter are colder than others, so we can also use temperature to define the third difference. We calculate for each county-month a measure of coldness, namely heating degree-days (HDD), as described in Section 3. The triple difference model using HDD is as follows:

$$\begin{aligned}
\log(m)_{jt} = & \alpha + \lambda_1 ShareGas_j \times \log(RelPrice_t) \times HDD_{jt} + \lambda_2 ShareGas_j \times \log(RelPrice_t) \\
& + \lambda_3 ShareGas_j \times HDD_{jt} + \lambda_4 \log(RelPrice_t) \times HDD_{jt} + \lambda_5 HDD_{jt} \\
& + \theta_1 Z_j \times \log(RelPrice_t) \times HDD_{jt} + \theta_2 Z_j \times \log(RelPrice_t) + \theta_3 Z_j \times HDD_{jt} \\
& + \theta_4 ShareGas_j \times \log(RelPrice_t) \times \overline{HDD}_j + \theta_5 \log(RelPrice_t) \times \overline{HDD}_j \\
& + \theta_6 Z_j \times \log(RelPrice_t) \times \overline{HDD}_j + \gamma_j + \tau_t + \delta X_{jt} + \epsilon_{jt}
\end{aligned} \tag{2}$$

The prediction is $\lambda_1 > 0$. Note that equation (2) controls for the county’s average HDD in winter, $\overline{HDD}_j$, in parallel to HDD_{jt} to adjust for systematic differences (e.g., demographics) between colder regions such as the Midwest and warmer ones such as the South. The results are similar if we omit these extra control variables, using average differences across places in the severity of their winters as additional identifying variation.

2.2 Assessing the income and substitution channels

An auxiliary outcome we examine is the average price of heating experienced by consumers. We calculate the weighted average of the local prices of natural gas and electricity, where weights are the local consumption of each energy source. A model analogous to equa-

tion (1) but using log average local price as the outcome is like the “first stage” if we were using instrumental variables estimation. We would expect $\beta = 1$ if our regressors were measured without error and if local and national average prices moved entirely in lockstep. The coefficient will be less than 1 if there is either measurement error or price variation specific to a locality, which we would expect due to local demand and regulatory factors plus a supply side that is not fully integrated across the US.

We also examine two other “1.5th” stage outcomes to gauge the importance of the substitution and income channels. First, we examine the (log) quantity of home energy use, combining gas and electricity. When the outcome is log energy use, the coefficient β from equation (1) can be interpreted as a price elasticity. We expect it to be negative: Consumers substitute away from heating when it becomes more expensive. The data on home energy use do not disaggregate it by purpose (e.g., heating, lighting). Thus, while the variation in the price of natural gas is mainly measuring variation in a household’s heating price, the outcome combines heating plus other energy uses, so the coefficient represents a lower bound magnitude for the price elasticity of heating demand. Natural gas’s home use is mostly for heating (space heating and water heating), with an additional small contribution from kitchen ranges and clothes dryers. Non-heating home energy needs such as lighting, refrigeration, and air conditioning predominantly use electricity throughout the US. Home heating is also the largest home energy use, accounting for 42% of annual home energy consumption, with water heating accounting for an additional 18% (RECS 2009). Other major categories are lighting and appliances (30%), refrigeration (5%), and air conditioning (6%).

Second, we examine how higher heating prices affect expenditures on home energy use, again with the caveat that we cannot distinguish spending on heating from other energy uses (although in winter months, heating accounts for the vast majority of energy use). If households are not cutting back one-for-one when the price rises, then we expect higher energy prices to lead to higher energy bills. Of course, we cannot decompose how much of the mortality effects are due to changes in the quantity of home heating versus changes in expenditures on heating since a price change generates both effects as a bundle.

2.3 Geographic variation in heating source

Natural gas and electricity are the two most common energy sources used for home heating, used respectively by 58% and 30% of households nationwide in 2000. Importantly for our purposes, there is considerable geographic variation in energy source; in some communities, almost every household uses natural gas for heating, and in other communities, almost no one does. Figure 1 shows the share of households using natural gas as their heating source across counties, based on 2000 US Census data.

Whether a locality uses natural gas, electricity, or another heating source is, of course, not random, and various factors explain the differences. Natural gas pipelines do not extend to some parts of the US, such as Maine. Areas that are well-suited for hydroelectric power generation have low electricity costs and thus rely more on electricity. For historical reasons, much of the Northeast uses heating oil, a petroleum product, instead of gas or electricity. Importantly, the geographic differences were determined long before the study period and are highly persistent. (The correlation between a county’s share using natural gas in 2000 and 2010 is 0.99). Being predetermined does not rule out that an area’s heating source is correlated with other factors affecting mortality, so the analysis controls for other locality characteristics in parallel to heating source.

2.4 Temporal variation in energy prices

Figure 2 plots the national prices of natural gas and electricity over the 2000 to 2010 study period. The data source is the US Energy Information Administration. (In this figure and throughout the paper, monetary amounts are in 2016 USD.) Natural gas is one of the fuel sources used in electricity generation, so the two prices co-move, but far from in lockstep. Electricity prices changed somewhat over the time period, while natural gas prices rose and then fell much more dramatically. As a result, the relative price of natural gas to electricity rose and then fell over the period.

Natural gas prices rose from 2004 to 2005 due in part to supply disruptions from major hurricanes along the Gulf coast (Hurricane Ivan in 2004 and Hurricanes Katrina and Rita in 2005) (Brown and Yücel 2008). In addition, increased efficiency of producing electricity from natural gas boosted demand for natural gas during the early 2000s (Hartley et al. 2008). The major reason for the drop in the price of natural gas in the mid-2000s was the sharp

increase in shale production of natural gas, which is also plotted in Figure 2.³

2.5 Home heating versus other heating

While we sometimes refer to our results as due to home heating, the analysis cannot isolate home heating from other indoor (e.g., workplace) heating. Some policy implications, such as whether to promote increased energy supply, are similar whether the channel is home heating or other indoor heating. For other policies, such as subsidies for consumer heating bills, it would be valuable to isolate heating costs at home, which our research design does not permit. A related, more minor limitation is that we cannot separate the effect of space heating versus water heating; the energy source is the same in most households (RECS 2014). Both types of heating likely affect health through similar mechanisms.

3 Data

Our analysis focuses on the contiguous US between 2000 and 2010. We exclude Hawaii and Alaska because our data source for temperature excludes them. The rest of this section describes our data sources, with further details in the appendix.

3.1 Mortality

We construct the mortality rate from restricted-use Vital Statistics microdata, specifically records for all deaths in the US, indicating the month and county of residence (and county of death), and cause of death. The data include the decedent's age, sex, race, and education level. We exclude counties with a small population over age 50, specifically those in the bottom tenth percentile of all counties, as they have few (often zero) deaths per month.

Following the literature, we age-adjust the mortality rate using population data from the National Cancer Institute's Surveillance Epidemiology and End Results program. Our main specifications examine the logarithm of the age-adjusted mortality rate, and we also report the results in levels.

We focus on causes of mortality that exhibit a high degree of excess winter mortality (EWM). Overall mortality is higher in winter than the rest of the year, but the pattern is more pronounced for some causes than others. We zero in on these causes because it is most

³Natural gas markets are not fully integrated globally. Pipeline capacity was a bottleneck to US exports in the late 2000s. Thus, natural gas prices fell in the US relative to other countries over this period (Hausman and Kellogg 2015).

plausible that they are exacerbated by exposure to cold and also because doing so increases statistical power. We use a data-driven approach to determine these causes. We collapse the data geographically to the entire US and estimate a regression of log age-adjusted mortality on a dummy for winter, separately for each of the National Center for Health Statistics (NCHS) 113 Selected Causes of Death. Causes with a large positive winter coefficient have more excess mortality in winter. We also estimate the model in levels to exclude minor causes that might have spuriously large coefficients. We select the causes whose *Winter* coefficients are in the top quartile in both levels and logs. This procedure identifies 16 causes. We exclude two causes, “deaths from smoke, fire, and flames” because its increase in winter is not due to a direct physiological effect of cold; and “all other diseases” (the residual category), because it is difficult to verify the mechanism for this “cause.” The remaining 14 causes fall within four alphabetic (i.e, broad) categories, and generally match the causes highlighted in the literature as exacerbated by cold (e.g., cardiovascular, respiratory). These high-EWM causes (hereafter, EWM causes) account for 61% of total mortality (and 63% of total mortality in winter). Appendix Table A1 lists the causes and their degree of EWM, and Appendix Figure A2 shows the seasonality for EWM and non-EWM causes.

3.2 Independent variables

To construct *ShareGas*, we use 2000 Decennial Census data. The Census longform asks the energy source for home heating, as does the American Community Survey (ACS), which has been fielded annually since 2005. We use the 2000 Census Summary Files that report aggregate data for each county. When our geographic unit is the Public Use Micro Area (PUMA), we construct each PUMA’s value of *ShareGas* from public use microdata.

RelPrice, the ratio of the price of gas to electricity, is constructed using monthly national price data from the US Energy Information Administration (EIA). We use national rather than local prices, as national prices are exogenous to a locality, while local prices are affected by local energy demand.⁴ For natural gas, we use the citygate price, which is the price faced by local distribution companies. We use the citygate rather than residential price because the latter incorporates fixed costs like the monthly fee to maintain a gas connection. Hence, the citygate price better captures variation in the marginal price faced by consumers.

⁴We investigated using pre-period local differences in the use of natural gas in electricity generation as an additional source of variation. The two prices co-move more if gas and electricity markets are interconnected in this way. However, this approach does not add statistical power.

For electricity, we use the residential price, as there are no citygate data available.

The correct specification depends on the timing of consumers’ response to *RelPrice*. We find that residential energy use responds to *RelPrice* with a lag of three months. This is similar to the finding in Auffhammer and Rubin (2018) that natural gas consumption responds to residential prices with a two-month lag.⁵ Consumers seem to cut back on usage only after seeing their energy bill, which typically arrives a few weeks after the billing period ends. In addition, the health effects of cutbacks in heating use or paying higher bills might not be instantaneous. Hence, we use the average of the three- and four-month lagged price to construct *RelPrice*. We obtain similar results when we use prices lagged one month less or an annual-level price series. We also estimate models that incorporate mortality effects in subsequent, post-winter months; the effect in subsequent months could be negative if deaths are hastened by a short duration (“harvesting”) or positive if the mortality effects materialize with a longer delay.

The analysis also uses temperature data. We start with the PRISM dataset of daily average temperature for gridpoints across the contiguous US spaced 4 kilometers apart (PRISM Climate Group 2004). We calculate the temperature for each census block and then use population weighting to construct the average for each county or other geographic unit. Our mortality data are at the month level, so we use the daily temperature data to construct heating degree-days (HDD) for the month. HDD is a commonly used measure of coldness — or need for heating — based on the idea that heating demand is linear in temperature when temperature falls below 65°F. That is, $HDD_{jt} = \sum_{x=1}^T \max\{65 - tmean_{jtx}, 0\}$ where *tmean* is the mean temperature of area *j* on day *x* of month *t*, and *T* is the number of days in month *t*.

Controlling for air pollution is potentially important because it is correlated with weather conditions and affects mortality (Ye et al. 2012). We use data from the Air Quality System of the US Environmental Protection Agency, aggregating the daily monitoring-station air quality indices (AQI) to the county-month level. We focus on particulate matter (2.5 micron and 10 micron, separately) and nitrogen dioxide, as these are the pollutants correlated with mortality; our results are similar if we control for all of the available AQIs.

Because a major housing market run-up and collapse occurred during the study period,

⁵By federal law, utilities must price the natural gas component of their service for cost-recovery only. Any shock to the citygate price not predicted in advance by the utilities thus influences the residential price one month later, explaining the additional one-month lag for citygate versus residential prices.

we control for a housing price index, available at the state-quarter level from the Federal Housing Finance Agency. Similarly, the Great Recession had different impacts across counties so we control for the unemployment rate (available at the county-month level from the Bureau of Labor Statistics) and the manufacturing sector share of total employee compensation (available at the state-quarter level from the Bureau of Economic Analysis). We also control for median household income and the population share age 70 and older, calculated from the 2000 Census, interacted with $\log(RelPrice)$. We show robustness to varying our set of control variables.

3.3 Other dependent variables

We examine intermediate outcomes to shed light on why heating prices affect mortality. We use local residential natural gas and electricity prices to compute the average (consumption-weighted) price of home energy. We also examine residential energy use, constructed as the sum of natural gas and electricity use. Price and usage data are aggregate state-month-level data from EIA.⁶

To measure household spending on home energy, we combine 2000 Census microdata (IPUMS version) and ACS data for 2005 to 2010. This analysis is conducted at the PUMA rather than county level, as the PUMA is the finest geographic identifier provided. For computational ease, the analysis collapses the data to the PUMA-year level.

4 Results

We first present results on the “first stage” and “1.5th stage” outcomes of home energy prices, quantity of energy consumed, and energy bills. We then present the mortality results.

4.1 Effect of heating price on energy use and spending

We use $ShareGas \times \log(RelPrice)$ as an exogenous source of variation in the home heating price faced by households. We do not have household-level data on energy prices, but we can use aggregate administrative data on residential energy prices to verify that our regressor is a good proxy for household prices.

The price variable is the weighted average price of residential natural gas and electricity prices. Each observation is a state-month. As shown in Table 1, columns 1 and 2, home en-

⁶Natural gas prices and quantities are provided on a volumetric basis. To make these data comparable across the sample, we use EIA data on the heat content of natural gas supplied to residential customers.

energy prices are strongly positively correlated with $ShareGas \times \log(RelPrice)$. In column 1, we include only state and month-year fixed effects. In column 2, we add the housing price index, unemployment rate, share of income from manufacturing, interactions of $\log(RelPrice)$ with median income and the share of people over age 70, and air pollution indices.

The coefficient on $ShareGas \times \log(RelPrice)$ is less than 1 for several reasons. First and foremost, the outcome is average *energy* prices, while the regressor is intended to proxy for average *heating* prices. In addition, the outcome is average prices weighted by usage, so it also incorporates any responses of usage to prices.⁷ Note that to convert our mortality results into an elasticity of mortality with respect to the heating price, the relevant scale factor is 1, not the smaller coefficient estimated here; a change in $ShareGas \times \log(RelPrice)$ can still be interpreted as a proportional change in the heating price faced by a household.

We next quantify how households' energy use responds to higher prices and then the impact on their energy bills. (In principle, once we know one of these numbers, we could calculate the other, but showing both is useful given that the data are available at different geographic levels and based on different samples.) We start by examining the impact on usage using EIA data, shown in Table 1, columns 3 and 4. As expected, higher prices lead to less consumption. Both the outcome and key regressor are in logs, so the coefficient represents an elasticity. The coefficient of -0.14 implies that households cut back usage quite a bit, but not one-for-one with price. To quantify the elasticity, one needs to scale the coefficient by the corresponding price-change coefficient from columns 1 and 2. We report this implied elasticity, which is around -0.35, at the bottom of the table. This elasticity is a similar magnitude as the winter natural gas demand elasticity for California estimated by Auffhammer and Rubin (2018). In Appendix Table A2, we show that the estimates based on our triple difference specification are similar.⁸

The elasticity having a magnitude smaller than 1 implies that households are spending more money on energy expenses when the heating price increases. We verify this using household-level Census/ACS data. Columns 5 and 6 of Table 1 show that the heating price shock is associated with a 24 log point increase in energy expenses. If the result is driven by changes in winter expenses, then the coefficient is an underestimate of the impact during winter months. (ACS does not release the survey month or distribution of months when

⁷Also, we construct *ShareGas* weighting each household equally, whereas EIA's usage-weighted measure implicitly weights bigger users more. There might also be some measurement error in *ShareGas*.

⁸Appendix Table A3 reports results varying how we construct *RelPrice*, in particular using different lags.

surveys are completed. The Census asks about annual spending on energy bills.) Column 7 and 8 examine the outcome in levels: a 10% increase in the price of heating is associated with a \$5 increase in the monthly home energy bill, averaged over the year. To help interpret these magnitudes, note that the relative price of natural gas fell by 42% (54 log points) between 2005 and 2010. This price decline led to a 12% or \$315 annual decrease in energy bills for natural gas users, using the estimates in columns 6 and 8, respectively.

To summarize, we find that households reduce usage in response to an increase in their heating price, but not fully, so they also experience a meaningful increase in energy bills when the price of heating increases.

4.2 Effect of heating price on mortality

We examine the effect of heating prices on the log of the age-adjusted mortality rate, following Stevens et al. (2015).⁹ We focus on “EWM causes of death,” that is, causes with a pronounced peak in winter. Focusing on EWM causes provides a more honed test of the hypothesis that heating prices affect deaths due to exposure to cold and increases statistical power. We report effects on all-cause mortality in Appendix Table A5.¹⁰

Table 2 shows that a higher heating price increases mortality from EWM causes. Column 1 includes as regressors only county and year-month fixed effects in addition to $ShareGas \times \log(RelPrice)$. Column 2 adds in our full set of control variables, listed earlier. In column 2 (our preferred specification), the elasticity of EWM mortality with respect to price is 0.057. Given that our EWM causes account for 63% of total mortality in winter, the implied elasticity of total mortality is 0.036, which is similar to the estimated elasticity of 0.030 when we directly examine all-cause mortality.¹¹

The next columns show the effects disaggregated by broad category: non-viral non-respiratory infections; neurological; circulatory; and respiratory. The overall effect on EWM mortality is mainly driven by circulatory and respiratory causes. Appendix Table A6 reports results separately for each of the 14 EWM causes. The largest effect size is seen for emphysema, other chronic lower respiratory diseases, acute myocardial infarction, and pneumonia.

⁹We show robustness to using the age-adjusted mortality rate in levels in Appendix Table A4.

¹⁰We pursued also estimating effects on morbidity using the Heath and Retirement Study and on hospitalizations using the National Inpatient Sample, but due to the smaller sample sizes, we are underpowered to detect even elasticities considerably larger than our mortality estimates.

¹¹When we estimate our main specification for non-EWM causes, the coefficient on $ShareGas \times \log(RelPrice)$ is 0.006 and statistically insignificant. As the income channel should affect non-EWM mortality too, this pattern is suggestive of the importance of the substitution channel.

Interestingly, the price of heating does not seem to exacerbate influenza deaths.

The effects we estimate are not due to deaths being moved earlier by just a short duration, or “harvesting.” Appendix Table A7 shows that the cumulative mortality effect is stable in magnitude when we incorporate effects in subsequent months. The cumulative effect is statistically significant when we add up to three subsequent months; there is not enough statistical power to determine at what point it becomes zero.

Appendix Tables A8 and A9 show robustness of the results to varying the definition of winter; excluding shale-gas-producing states; using residential instead of citygate, or annual instead of monthly, natural gas prices; population-weighting the regressions; dropping the Great Recession period; controlling for the state’s per capita spending on the Low Income Home Energy Assistance Program (LIHEAP)¹²; and varying the main set of control variables.

We next bring in data for non-winter months to estimate triple difference models. We use either *Winter* or *HDD* as the third difference. Table 2, column 7 shows that the effect of heating prices on mortality is stronger in winter than the rest of the year. Reassuringly, the coefficient on $ShareGas \times \log(RelPrice)$ is close to zero: the price of heating has no effect on mortality in non-winter months.

Using *HDD*, we find that the price of heating increases mortality more in colder months. *HDD* is normalized so that a unit change is the difference between every day in the month being 65°F or above and being 32°F. A one-unit increase in HDD_{jt} , relative to the county’s average winter *HDD*, which we control for in parallel to HDD_{jt} , leads to a 0.084 higher elasticity of mortality with respect to heating price.

The results are similar but somewhat weaker when we do not control for average *HDD* (see Appendix Table A10), which is consistent with previous findings that, due to adaptation (e.g., better insulated homes in colder places), atypical cold for an area is what especially affects mortality (Eurowinter Group 1997). As another reassuring placebo test, when $HDD = 0$ in this specification, the heating price does not affect mortality.

Table 3 returns to the difference-in-differences model to examine heterogeneous effects

¹²LIHEAP provides assistance with energy bills to low-income households. On average between 2001 and 2010, 4.5% of US households received LIHEAP heating assistance per year, which is 23% of households below 150% of the poverty line. LIHEAP pays eligible households a preset amount each year based on income and household size, and, depending on the state, also fuel type or the last year’s utility bills. Arizona is, to our knowledge, the only state that varies the amount based on contemporaneous bills or prices (LIHEAP Clearinghouse 2010). LIHEAP state-year spending data are from the Department of Health and Human Services.

by poverty. Heating bills comprise a larger share of expenditures for the poor. For this and other reasons, we expect heating prices to have larger effects on mortality among the poor. Columns 1 to 4 each use a different poverty proxy. In column 1, the proxy is whether the county's median income is in the bottom half of the distribution across counties. Columns 2 and 3 use the proportion of households in the county that are below 150% of the federal poverty line, as either a continuous variable or an indicator for the county having a below-median proportion of households below the income threshold. Column 4 uses the decedent's education level, specifically an indicator for no high school degree. Across the board, the point estimates suggest larger effects among the poor, but the finding is only statistically significant in column 2 ($p < 0.10$) and column 3 ($p < 0.05$), which use the proportion of households below 150% of the poverty line.

Another dimension of heterogeneity we examined is sex. Table 3, column 5, reports that the mortality effects do not significantly differ by sex.

5 Conclusion

This paper finds that winter mortality is lower when the price of heating is lower. To put the estimated elasticity of all-cause mortality with respect to the price of heating of 0.03 in context, the price of natural gas relative to electricity fell by 42% between 2005 to 2010. Our findings imply that this price decline caused a 1.6% decrease in the winter mortality rate for households using natural gas for heating. Given that 58% of American households use natural gas for heating, the drop in natural gas prices lowered the US winter mortality rate by 0.9%, or, equivalently, the annual mortality rate by 0.4%. This represents over 11,000 deaths per year.

This effect size is large enough that it should not be ignored when assessing the net health effects of shale production of natural gas. The findings also highlight the health benefits of other policies to reduce home energy costs, particularly for low-income households.

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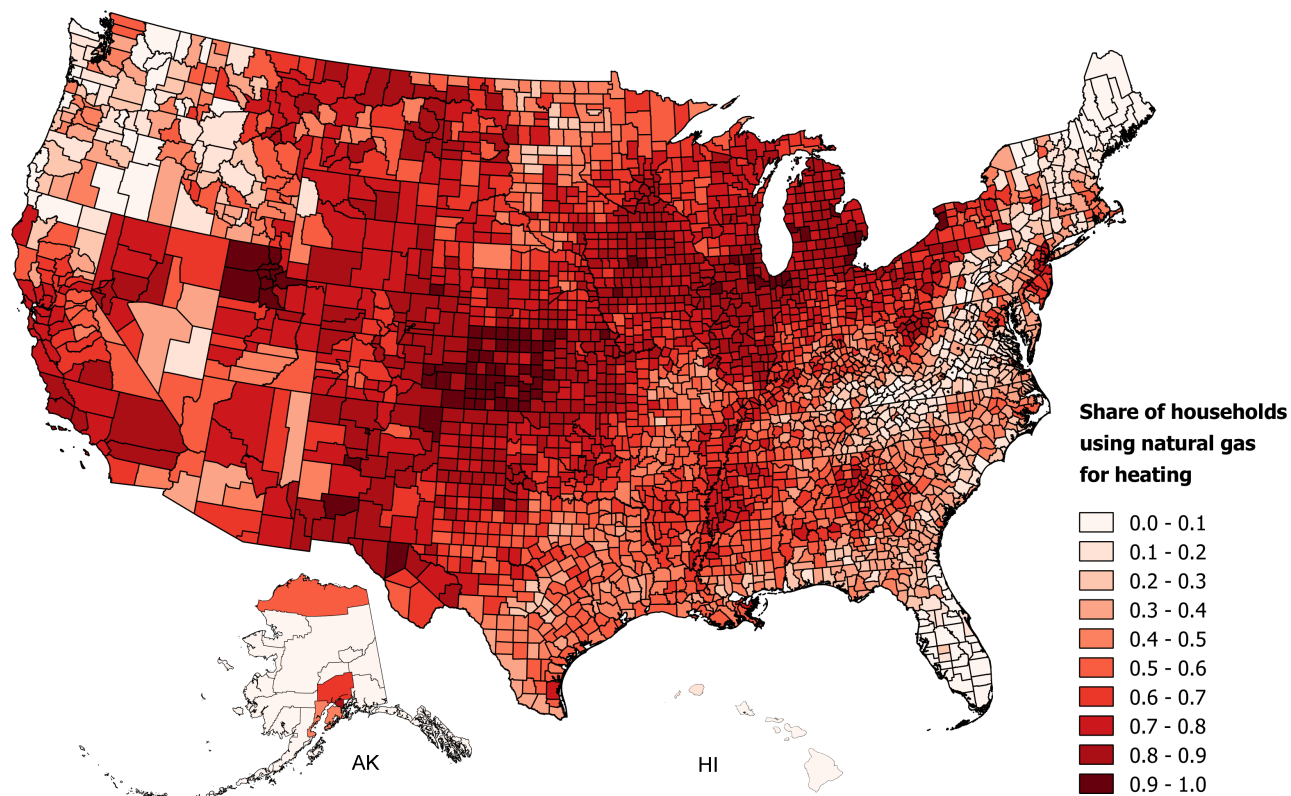
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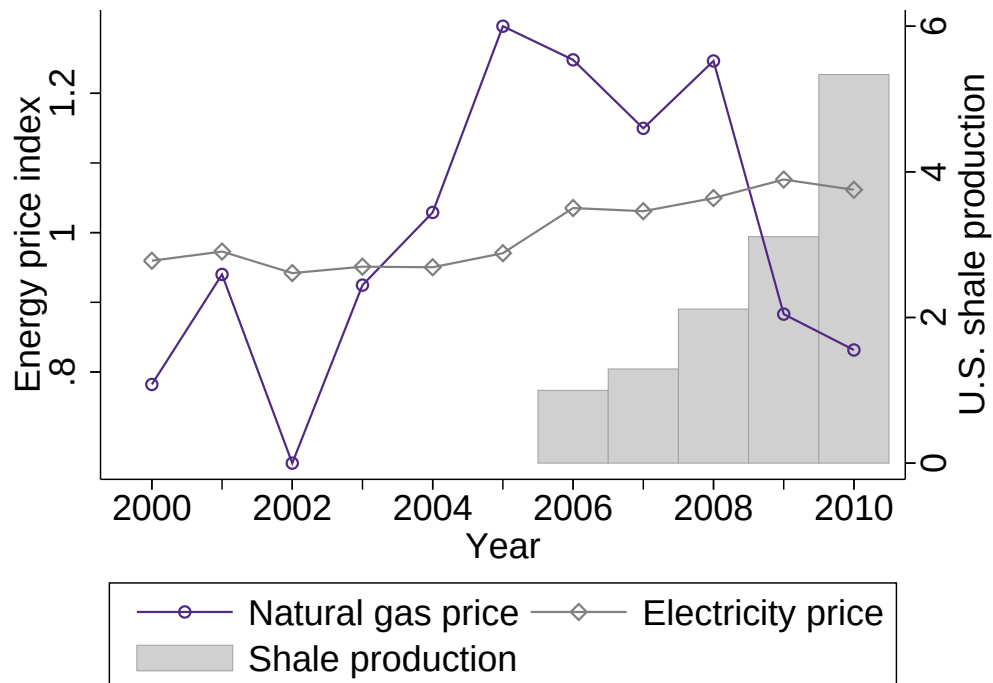
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Figure 1: Share of households using natural gas for heating, by US county



Notes: The figure shows the proportion of occupied housing units in each county that report using natural gas as their main heating source. Data are from the 2000 US Census.

Figure 2: US natural gas and electricity prices, 2000 to 2010



Notes: The data series depicted with lines are the national prices of natural gas and electricity, normalized by their respective averages between 2000 and 2010 (left axis). National shale gas production in trillion cubic feet is shown as the bar chart (right axis). Data are from the US Energy Information Administration.

Table 1: Effect of heating price on energy use and energy spending

	Dependent variable:							
	Log of average electricity and gas price		Log of total energy consumption		Log of total monthly energy bill		Total monthly energy bill	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ShareGas $\times$ Log(RelPrice)	0.40*** [0.068]	0.39*** [0.074]	-0.14** [0.042]	-0.14** [0.050]	0.25*** [0.044]	0.24*** [0.050]	53.2*** [11.5]	48.7*** [12.3]
Observations	2,695	2,695	2,695	2,695	14,385	14,385	14,385	14,385
Mean price/quantity	21.1	21.1	22.1	22.1	231.6	231.6	231.6	231.6
Basic fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
All other controls	No	Yes	No	Yes	No	Yes	No	Yes
Implied elasticity			-0.36	-0.35				

Notes: Standard errors clustered by state in brackets. Asterisks denote significance: * $p < .10$, ** $p < .05$, *** $p < .01$. Columns 1 to 4: The sample comprises state-year-months in the contiguous U.S. for winter months (November–March) between 2000 and 2010. Outcomes are constructed from EIA data. Columns 5 to 8: The sample comprises PUMA-years in the contiguous U.S. included in the 2000 Census and the ACS PUMS data between 2005 and 2010. Outcomes are constructed from Census/ACS data. *Log(RelPrice)* is the log of the ratio of the US monthly citygate price of natural gas, averaged over the three- and four-month lag, to the US monthly residential price of electricity, also averaged over the three- and four-month lag. *ShareGas* is the proportion of occupied housing units in the state or PUMA in 2000 with natural gas as their main heating source. Average electricity and gas price is the state’s consumption-weighted average of the residential prices of electricity and gas, in dollars per million British Thermal Units (BTUs). Total energy consumption is the state’s total delivery of natural gas and electricity to residential consumers, in trillion BTUs. Total monthly energy bill is the mean monthly bill from electricity, gas and other fuels in the PUMA. *Basic fixed effects* are state and year-month fixed effects for columns 1 to 4, and PUMA and year fixed effects for columns 5 to 8. *All other controls* are the interactions of *log(RelPrice)* with the log of the median state or PUMA household income in 1999 and the share of people aged 70 and above in 2000, the state housing price index, the unemployment rate, the state’s manufacturing sector share of total employee compensation, and the AQIs for PM_{2.5}, PM₁₀, and NO₂. Implied elasticity is the ratio of the coefficient reported in that column to the corresponding coefficient from the first two columns (the “first stage”). Monetary variables are in constant 2016 US dollars.

Table 2: Effect of heating price on mortality from EWM causes of death

	Dependent variable: Log of EWM-causes mortality rate							
	All EWM causes	All EWM causes	Group A: Non-viral, non- respiratory infections	Group G: Neurologi- cal diseases	Group I: Circulatory system diseases	Group J: Respiratory system diseases	All EWM causes	All EWM causes
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ShareGas $\times$ Log(RelPrice)	0.052** [0.022]	0.057*** [0.021]	0.021 [0.027]	0.016 [0.034]	0.054** [0.024]	0.10*** [0.024]	-0.013 [0.015]	0.080** [0.039]
ShareGas $\times$ Log(RelPrice) $\times$ Winter							0.073*** [0.019]	
ShareGas $\times$ Log(RelPrice) $\times$ HDD								0.084*** [0.031]
Observations	152,927	152,927	108,659	110,742	151,589	148,583	366,668	366,668
Mean mortality rate	577.6	577.6	74.16	74.01	371.8	259.8	527.8	527.8
Basic fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
All other controls	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Standard errors clustered by state in brackets. Asterisks denote significance: * $p < .10$, ** $p < .05$, *** $p < .01$. The sample comprises county-year-months in the contiguous U.S. between 2000 and 2010. In columns 1 to 6, the sample is restricted to winter months (November–March). Mortality rates are age-adjusted mortality rates expressed as annual deaths per 100,000 population; see data appendix for further details. *ShareGas* is the proportion of occupied housing units in the county in 2000 with natural gas as their main heating source. *Log(RelPrice)* is the log of the ratio of the monthly citygate price of natural gas in the US, averaged over the three- and four-month lag, to the corresponding residential price of electricity. *Winter* is a binary variable that equals one in winter months (November to March). *HDD* is the number of heating degree-days in the county for the month, based on a threshold of 65°F, in units of °F-days divided by 1000, and scaled to a 30-day month. *Basic fixed effects* are county and year-month fixed effects. Columns 1 to 6: *All other controls* are the interactions of *log(RelPrice)* with the log of the median county household income in 1999 and the share of people aged 70 and above in 2000, the state housing price index, the unemployment rate, the state’s manufacturing sector share of total employee compensation, and the AQIs for PM_{2.5}, PM₁₀, and NO₂. Column 7 and 8: *All other controls* is the above set plus the following: all possible two-way interactions between *ShareGas*, *log(RelPrice)*, and the triple difference variable (either *Winter* or *HDD*), unless collinear with year-month fixed effects; and the two- and three-way interactions among *log(RelPrice)*, *Winter/HDD*, and each of the log of the median county household income in 1999 and the share of people aged 70 and above in 2000. Column 8 also includes *HDD*; the interaction of the average county HDD in winter months with *log(RelPrice)*; and the three-way interactions of the average county HDD in winter months, *log(RelPrice)*, and each of *ShareGas*, the log of the median county household income in 1999, and the share of people aged 70 and above in 2000.

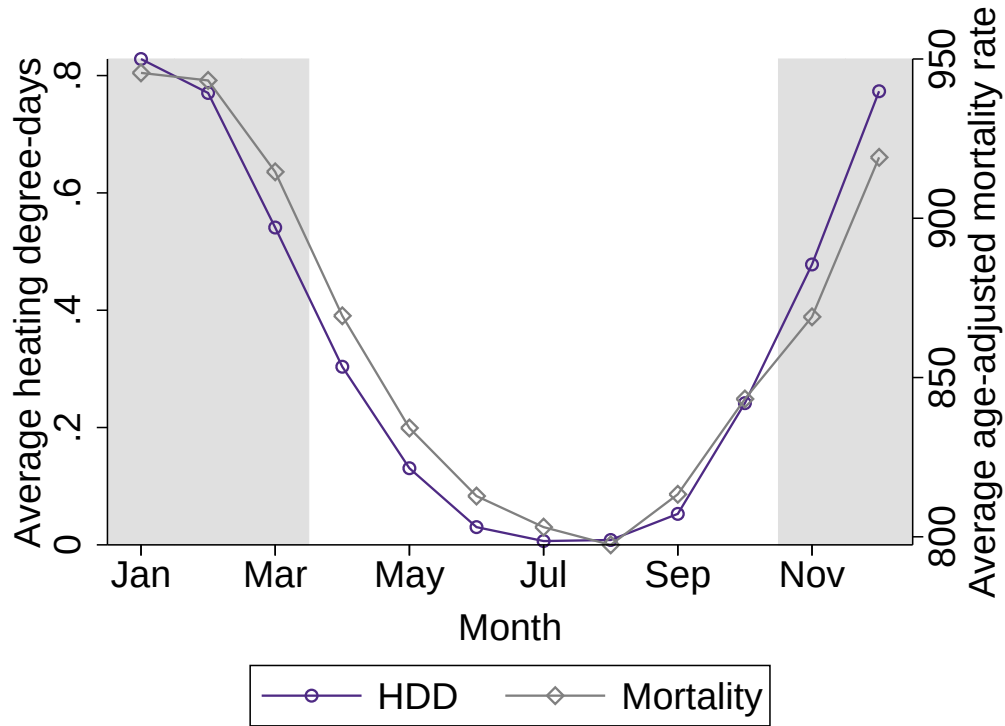
Table 3: Heterogeneous effects on mortality

	Dependent variable: Log of all-EWM-causes mortality rate Trait is:				
	Below- median county income	Proportion below 150% of poverty line	Above- median proportion below 150% of poverty line	No high school degree	Male
	(1)	(2)	(3)	(4)	(5)
ShareGas $\times$ Log(RelPrice) $\times$ Trait	0.019 [0.035]	0.34* [0.20]	0.060** [0.030]	0.038 [0.045]	0.013 [0.027]
ShareGas $\times$ Log(RelPrice)	0.047** [0.019]	-0.025 [0.045]	0.033* [0.019]	0.019 [0.052]	0.057*** [0.019]
Observations	152,927	152,927	152,927	284,700	300,311
Mean mortality rate	577.6	577.6	577.6	999.4	605.3
Implied effect for Trait = 1	0.07* [0.03]	0.31* [0.16]	0.09*** [0.03]	0.06 [0.06]	0.07** [0.03]

Notes: Standard errors clustered by state in brackets. Asterisks denote significance: * $p < .10$, ** $p < .05$, *** $p < .01$. For columns 1 to 3, the sample comprises county-year-months in the contiguous U.S. for winter months (November–March) between 2000 and 2010. For columns 4 and 5, the sample comprises county-year-months-education group and county-year-months-sex group respectively for winter months. Mortality rates are age-adjusted mortality rates expressed as annual deaths per 100,000 population; see data appendix for further details. *ShareGas* is the proportion of occupied housing units in the county in 2000 with natural gas as their main heating source. *Log(RelPrice)* is the log of the ratio of the monthly citygate price of natural gas in the US, averaged over the three- and four-month lag, to the corresponding residential price of electricity. Column 1: *Trait* is an indicator variable that equals one if the county’s median household income is below the median of all counties in the sample in 1999. Column 2: *Trait* is the proportion of households in the county with income in 1999 below 150 percent of the poverty threshold. Column 3: *Trait* is an indicator variable that equals one if the proportion from column 2 is above the median of all counties in the sample. Column 4: *Trait* is an indicator variable that equals one for the subgroup that did not complete high school. Column 5: *Trait* is an indicator variable that equals one for the male population. All columns include all controls from column 2 of Table 2, the main effect for *Trait*, and the interaction of each control variable with *Trait*.

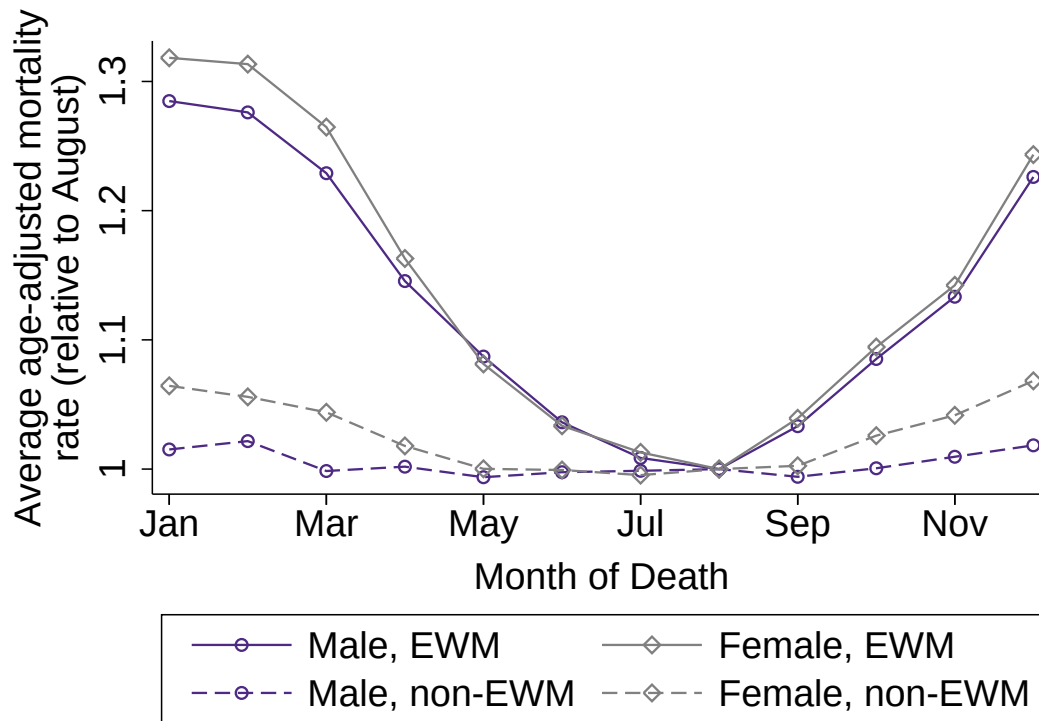
A Appendix figures and tables

Appendix Figure A1: Heating degree-days and monthly mortality in the US



Notes: Average heating degree-days (HDD) and average age-adjusted mortality rates across US counties (excluding Hawaii and Alaska) between 2000 and 2010 plotted by month. Average HDD is computed using temperature data from the PRISM Climate Group, and is based on a threshold of 65°F, in units of °F-days divided by 1000, and scaled to a 30-day month. Average age-adjusted mortality rates are computed using the NCHS mortality data and expressed per 100,000 population on an annualized basis. Months we define as winter in our analysis (November–March) are shaded in the background.

Appendix Figure A2: Seasonality in mortality for EWM and non-EWM causes



Notes: Average age-adjusted mortality rates across US counties (excluding Hawaii and Alaska) between 2000 and 2010, broken down by sex and EWM versus other causes. EWM causes are those that exhibit a strong pattern of higher mortality in winter than the rest of the year, as described in the text; see data appendix for further details. We normalize each series by its value in August (the month with the lowest all-cause mortality rate). Age-adjusted mortality rates are computed using the NCHS mortality data.

Appendix Table A1: Causes of death exhibiting high excess winter mortality

Cause of death (ICD-10 codes)	Mean monthly mortality rate	Level coefficient	Log coefficient
Septicemia (A40-A41)	0.95	0.14	0.14
Parkinson's disease (G20-G21)	0.53	0.08	0.16
Alzheimer's disease (G30)	1.92	0.36	0.18
Acute myocardial infarction (I21-I22)	4.34	0.62	0.14
All other forms of chronic ischemic heart disease (I20, I25.1-I25.9)	6.32	0.80	0.12
Heart failure (I50)	1.61	0.21	0.13
Cerebrovascular diseases (I60-I69)	4.12	0.52	0.12
Atherosclerosis (I70)	0.30	0.04	0.14
Influenza (J09-J11)	0.04	0.06	2.21
Pneumonia (J12-J18)	1.63	0.58	0.34
Emphysema (J43)	0.38	0.08	0.21
Other chronic lower respiratory diseases (J44, J47)	3.11	0.63	0.20
Pneumonitis due to solids and liquids (J69)	0.47	0.09	0.18
Other diseases of respiratory system (J00-J06, J30-J39, J67, J70-J98)	0.77	0.11	0.14
All other diseases (Residual)*	6.17	0.80	0.13
Accidental exposure to smoke, fire and flames (X00-X09)*	0.09	0.05	0.56

Notes: Mortality rates are expressed per 100,000 population and computed using the NCHS mortality data. The 75th percentile of level and log coefficient are 0.02 and 0.12, respectively. We remove *All other diseases* and *Accidental exposure to smoke, fire and flames* (marked with *) when we analyze mortality from high-EWM causes. See the data appendix for further details on the selection of high-EWM causes of deaths.

Appendix Table A2: Triple difference estimates of effects on average energy price and consumption

	Dependent variable: Log of average electricity and gas price		Dependent variable: Log of total energy consumption	
	(1)	(2)	(3)	(4)
ShareGas $\times$ Log(RelPrice) $\times$ Winter	0.36*** [0.048]		-0.12* [0.050]	
ShareGas $\times$ Log(RelPrice) $\times$ HDD		0.36*** [0.074]		-0.091 [0.067]
Observations	6,468	6,468	6,468	6,468
Mean price/quantity	25.5	25.5	16.0	16.0
Implied elasticity			-0.34	-0.25

Notes: Standard errors clustered by state in brackets. Asterisks denote significance: * $p < .10$, ** $p < .05$, *** $p < .01$. The sample comprises state-year-months in the contiguous U.S. between 2000 and 2010. Average electricity and gas price is the state's consumption-weighted average of the residential prices of electricity and gas, in dollars per million BTUs. Total energy consumption is the state's total delivery of natural gas and electricity to residential consumers, in trillion BTUs. *ShareGas* is the proportion of occupied housing units in the state in 2000 with natural gas as their main heating source. *Log(RelPrice)* is the log of the ratio of the monthly citygate price of natural gas in the US, averaged over the three- and four-month lag, to the corresponding residential price of electricity. *Winter* is a binary variable that equals one in winter months (November to March). *HDD* is the number of heating degree-days in the county for the month, based on a threshold of 65°F, in units of °F-days divided by 1000, and scaled to a 30-day month. Monetary variables are in constant 2016 US dollars. Implied elasticity is the ratio of the coefficient reported in that column to the corresponding coefficient from the first two columns (the "first stage"). All columns include covariates analogous to those used in columns 7 and 8 of Table 2.

Appendix Table A3: Effect of heating price on energy consumption, based on alternative *RelPrice* definitions

	Dependent variable: Log of total energy consumption						
	0 lags (contem- poraneous)	1 lag	2 lags	3 lags	4 lags	5 lags	6 lags
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
<i>Panel A: RelPrice constructed based on residential gas price, at indicated lag.</i>							
ShareGas $\times$ Log(RelPrice)	-0.18 [0.099]	-0.24* [0.12]	-0.38* [0.16]	-0.35* [0.16]	-0.27 [0.15]	-0.17 [0.11]	-0.15 [0.11]
Observations	2,695	2,695	2,695	2,695	2,695	2,695	2,695
Mean quantity	22.1	22.1	22.1	22.1	22.1	22.1	22.1
Implied elasticity	-0.23	-0.33	-0.59	-0.68	-0.58	-0.40	-0.41
<i>Panel B: RelPrice constructed based on citygate gas price, at indicated lag.</i>							
ShareGas $\times$ Log(RelPrice)	-0.023 [0.058]	-0.0014 [0.052]	-0.027 [0.052]	-0.12* [0.047]	-0.15* [0.055]	-0.12 [0.063]	-0.13 [0.069]
Observations	2,695	2,695	2,695	2,695	2,695	2,695	2,695
Mean quantity	22.1	22.1	22.1	22.1	22.1	22.1	22.1
Implied elasticity	-0.053	-0.0035	-0.076	-0.31	-0.39	-0.38	-0.46

Notes: Standard errors clustered by state in brackets. Asterisks denote significance: * $p < .10$, ** $p < .05$, *** $p < .01$. The sample comprises state-year-months in the contiguous U.S. for winter months (November–March) between 2000 and 2010. Total energy consumption is the state’s total delivery of natural gas and electricity to residential consumers, in trillion BTUs. *ShareGas* is the proportion of occupied housing units in the state in 2000 with natural gas as their main heating source. *Log(RelPrice)* is the log of the ratio of the monthly residential or citygate price of natural gas in the US, lagged by the number of months indicated in each column, to the corresponding residential price of electricity. Monetary variables are in constant 2016 US dollars. All columns include all controls from Table 1. Implied elasticity is the ratio of the coefficient in that column to the corresponding coefficient for the “first stage” (not shown).

Appendix Table A4: Effect of heating price on mortality from high-EWM causes of death using mortality rate in levels

	Dependent variable: EWM-causes mortality rate							
	All EWM causes	All EWM causes	Group A: Non-viral, non- respiratory infections	Group G: Neurologi- cal diseases	Group I: Circulatory system diseases	Group J: Respiratory system diseases	All EWM causes	All EWM causes
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ShareGas $\times$ Log(RelPrice)	32.1*** [11.3]	30.4*** [11.3]	0.14 [2.80]	-3.38 [2.57]	16.9** [8.35]	23.4*** [6.15]	-2.75 [6.51]	27.9 [22.1]
ShareGas $\times$ Log(RelPrice) $\times$ Winter							34.2*** [10.0]	
ShareGas $\times$ Log(RelPrice) $\times$ HDD								36.7** [15.4]
Observations	153,340	153,340	153,340	153,340	153,340	153,340	368,016	368,016
Mean mortality rate	576.0	576.0	52.55	53.45	367.5	251.7	525.9	525.9
Basic fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
All other controls	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Standard errors clustered by state in brackets. Asterisks denote significance: * $p < .10$, ** $p < .05$, *** $p < .01$. The sample comprises county-year-months in the contiguous U.S. between 2000 and 2010. In columns 1 to 6, the sample is restricted to winter months (November–March). Mortality rates are age-adjusted mortality rates expressed as annual deaths per 100,000 population; see data appendix for further details. *ShareGas* is the proportion of occupied housing units in the county in 2000 with natural gas as their main heating source. *Log(RelPrice)* is the log of the ratio of the monthly citygate price of natural gas in the US, averaged over the three- and four-month lag, to the corresponding residential price of electricity. *Winter* is a binary variable that equals one in winter months (November to March). *HDD* is the number of heating degree-days in the county for the month, based on a threshold of 65°F, in units of °F-days divided by 1000, and scaled to a 30-day month. *Basic fixed effects* are county and year-month fixed effects. Columns 1 to 6: *All other controls* are the interactions of *log(RelPrice)* with the log of the median county household income in 1999 and the share of people aged 70 and above in 2000, the state housing price index, the unemployment rate, the state’s manufacturing sector share of total employee compensation, and the AQIs for PM_{2.5}, PM₁₀, and NO₂. Column 7 and 8: *All other controls* is the above set plus the following: all possible two-way interactions between *ShareGas*, *log(RelPrice)*, and the triple difference variable (either *Winter* or *HDD*), unless collinear with year-month fixed effects; and the two- and three-way interactions among *log(RelPrice)*, *Winter/HDD*, and each of the log of the median county household income in 1999 and the share of people aged 70 and above in 2000. Column 8 also includes *HDD*; the interaction of the average county HDD in winter months with *log(RelPrice)*; and the three-way interactions of the average county HDD in winter months, *log(RelPrice)*, and each of *ShareGas*, the log of the median county household income in 1999, and the share of people aged 70 and above in 2000.

Appendix Table A5: Effect of heating price on all-cause mortality

	Dependent variable: Log of mortality rate				Dependent variable: Mortality rate			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ShareGas $\times$ Log(RelPrice)	0.021 [0.016]	0.030* [0.016]	-0.011 [0.0098]	0.046* [0.026]	29.1** [13.8]	32.6** [14.3]	-6.68 [7.86]	42.6* [24.7]
ShareGas $\times$ Log(RelPrice) $\times$ Winter			0.042** [0.016]				39.6*** [14.4]	
ShareGas $\times$ Log(RelPrice) $\times$ HDD				0.042* [0.024]				41.4* [21.5]
Observations	153,296	153,296	367,905	367,905	153,340	153,340	368,016	368,016
Mean mortality rate	929.5	929.5	872.6	872.6	929.2	929.2	872.3	872.3
Basic fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
All other controls	No	Yes	Yes	Yes	No	Yes	Yes	Yes

Notes: Standard errors clustered by state in brackets. Asterisks denote significance: * $p < .10$, ** $p < .05$, *** $p < .01$. The sample comprises county-year-months in the contiguous U.S. between 2000 and 2010. In columns 3, 4, 7 and 8, the sample is restricted to winter months (November–March). Mortality rates are age-adjusted mortality rates expressed as annual deaths per 100,000 population; see data appendix for further details. *ShareGas* is the proportion of occupied housing units in the county in 2000 with natural gas as their main heating source. *Log(RelPrice)* is the log of the ratio of the monthly citygate price of natural gas in the US, averaged over the three- and four-month lag, to the corresponding residential price of electricity. *Winter* is a binary variable that equals one in winter months (November to March). *HDD* is the number of heating degree-days in the county for the month, based on a threshold of 65°F, in units of °F-days divided by 1000, and scaled to a 30-day month. *Basic fixed effects* are county and year-month fixed effects. Columns 1, 2, 5, and 6: *All other controls* are the interactions of *log(RelPrice)* with the log of the median county household income in 1999 and the share of people aged 70 and above in 2000, the state housing price index, the unemployment rate, the state’s manufacturing sector share of total employee compensation, and the AQIs for PM_{2.5}, PM₁₀, and NO₂. Column 3, 4, 7, and 8: *All other controls* is the above set plus the following: all possible two-way interactions between *ShareGas*, *log(RelPrice)*, and the triple difference variable (either *Winter* or *HDD*), unless collinear with year-month fixed effects; and the two- and three-way interactions among *log(RelPrice)*, *Winter/HDD*, and each of the log of the median county household income in 1999 and the share of people aged 70 and above in 2000. Columns 4 and 8 also includes *HDD*; the interaction of the average county HDD in winter months with *log(RelPrice)*; and the three-way interactions of the average county HDD in winter months, *log(RelPrice)*, and each of *ShareGas*, the log of the median county household income in 1999, and the share of people aged 70 and above in 2000.

Appendix Table A6: Effect of heating price on mortality, by specific cause of death

Dependent variable: Log of specified disease mortality rate			
Septicemia	0.021 [0.027] {74.2}	Atherosclerosis	0.045 [0.057] {45.9}
Parkinson's disease	0.041 [0.031] {32.3}	Influenza	-0.20 [0.16] {27.3}
Alzheimer's disease	0.029 [0.037] {63.2}	Pneumonia	0.099*** [0.034] {104.9}
Acute myocardial infarction	0.10*** [0.036] {107.3}	Emphysema	0.14*** [0.047] {29.8}
Chronic ischemic heart disease	0.078** [0.030] {158.0}	Other chronic lower respiratory diseases	0.11*** [0.027] {114.2}
Heart failure	0.051* [0.026] {137.4}	Pneumonitis (solids and liquids)	0.039 [0.047] {44.4}
Cerebrovascular diseases	0.076** [0.034] {114.4}	Other respiratory diseases	0.047 [0.030] {107.4}

Notes: Each cell shows the result from a separate regression, and reports the coefficient on $ShareGas \times \log(RelPrice)$, the corresponding standard error clustered by state in square brackets, and the mean mortality rate of the specified cause in curly brackets. Asterisks denote significance: * $p < .10$, ** $p < .05$, *** $p < .01$. The sample comprises county-year-months in the contiguous U.S. for winter months (November–March) between 2000 and 2010. Mortality rates are age-adjusted mortality rates expressed as annual deaths per 100,000 population; see data appendix for further details. *ShareGas* is the proportion of occupied housing units in the county in 2000 with natural gas as their main heating source. *Log(RelPrice)* is the log of the ratio of the monthly citygate price of natural gas in the US, averaged over the three- and four-month lag, to the corresponding residential price of electricity. All columns include all controls from column 2 of Table 2.

Appendix Table A7: Dynamic effects of heating price on mortality

	Dependent variable: Log of all-EWM-causes mortality rate					
	(1)	(2)	(3)	(4)	(5)	(6)
Contemporaneous effect	-0.012 [0.053]	0.055 [0.055]	-0.029 [0.054]	-0.0043 [0.056]	-0.027 [0.061]	-0.0035 [0.057]
Effect on mortality 1 month after	0.066 [0.053]	-0.036 [0.080]	0.11 [0.094]	0.038 [0.085]	0.095 [0.10]	0.075 [0.098]
Effect on mortality 2 months after		0.046 [0.056]	-0.13 [0.10]	-0.016 [0.098]	-0.086 [0.11]	-0.11 [0.11]
Effect on mortality 3 months after			0.13** [0.063]	-0.026 [0.091]	0.090 [0.11]	0.15 [0.12]
Effect on mortality 4 months after				0.043 [0.046]	-0.13 [0.10]	-0.18 [0.14]
Effect on mortality 5 months after					0.11* [0.064]	0.16 [0.12]
Effect on mortality 6 months after						-0.030 [0.059]
Observations	183,510	214,043	244,552	275,071	305,602	336,113
Cumulative effect	0.05** [0.02]	0.07** [0.03]	0.08** [0.03]	0.03 [0.03]	0.05 [0.04]	0.05 [0.04]

Notes: Standard errors clustered by state in brackets. Asterisks denote significance: * $p < .10$, ** $p < .05$, *** $p < .01$. The sample comprises county-year-months in the contiguous U.S. between 2000 and 2010. The sample is restricted to months November to April in column 1, November to May in column 2, November to June in column 3, November to July in column 4, November to August in column 5, and November to September in column 6. The specification used is $\log(m_{jt}) = \sum_{k=0}^K \beta_k \text{ShareGas}_j \times \log(\text{RelPrice}_{t-k}) \times \text{MonthofEffect}_k + \gamma_k \text{ShareGas}_j \times \log(\text{RelPrice}_{t-k}) + \text{Controls} + \epsilon_{jt}$, where MonthofEffect_0 takes on a value of one in the months of November to March; MonthofEffect_1 takes on a value of one in the months of December to April; MonthofEffect_2 takes on a value of one in the months of January to May; MonthofEffect_3 takes on a value of one in the months of February to June; MonthofEffect_4 takes on a value of one in the months of March to July; MonthofEffect_5 takes on a value of one in the months of April to August; MonthofEffect_6 takes on a value of one in the months of May to September; and *Controls* are all controls from column 2 of Table 2 and are fully interacted with the MonthofEffect_k dummies. K , the total number of months after the contemporaneous effect, is 1 in column 1, 2 in column 2, and so on. The coefficients shown are β_k 's, the effect of the winter price of heating on winter mortality k months after winter, after accounting for intertemporal correlation (since we estimate the β_k 's jointly), and after removing the effect on mortality in irrelevant months through MonthofEffect_k dummies (e.g., April is not a winter month, so is not relevant for the contemporaneous effect). *Cumulative effect* is the sum of the β_k 's. All other definitions not noted above are as in column 2 of Table 2.

Appendix Table A8: Effect of heating price on mortality: Robustness checks

	Dependent variable: Log of all-EWM-causes mortality rate		
	Difference-in-differences (1)	Triple difference using winter (2)	Triple difference using HDD
Winter defined as December to March	0.048** [0.022]	0.065*** [0.021]	n/a
Winter defined as December to February	0.064** [0.028]	0.078*** [0.027]	n/a
Exclude fracking states	0.054** [0.021]	0.067*** [0.019]	0.096*** [0.030]
Use residential gas price, averaged over 2nd and 3rd lags	0.077** [0.031]	0.044 [0.036]	0.071 [0.056]
Use annual residential gas price	0.11** [0.041]	0.12*** [0.037]	0.073 [0.061]
Weight by population in 2000	0.049*** [0.016]	0.040*** [0.015]	0.050** [0.023]
Exclude Great Recession	0.035 [0.021]	0.067*** [0.020]	0.077** [0.031]
Control for Log(LIHEAP per capita)	0.056** [0.021]	0.073*** [0.019]	0.084*** [0.031]
Control for all pollutants	0.056** [0.021]	0.073*** [0.019]	0.085*** [0.031]

Notes: Each cell shows the result from a separate regression, and reports the coefficient on $ShareGas \times \log(RelPrice)$ (column 1), $ShareGas \times \log(RelPrice) \times Winter$ (column 2), or $ShareGas \times \log(RelPrice) \times HDD$ (column 3). The corresponding standard error, clustered by state, is shown in brackets. Asterisks denote significance: * $p < .10$, ** $p < .05$, *** $p < .01$. Each row shows a change in specification compared to columns 2, 7, and 8 of Table 2. Row 1, column 1: The sample additionally excludes November. Row 1, column 2: The sample excludes November, and uses December to March as winter months in the triple difference. Row 2, column 1: The sample additionally excludes November and March. Row 2, column 2: The sample excludes November and March, and uses December to February as winter months in the triple difference. Rows 1 and 2, column 3: The triple difference using HDD is the same as in the main specification since HDD is defined independently of winter. Row 3: The sample additionally excludes Arkansas, Louisiana, North Dakota, Oklahoma, Pennsylvania, Texas, and West Virginia, which are the states with significant production of shale natural gas. Row 4: $RelPrice$ is constructed as the ratio of the monthly residential price of natural gas in the US, averaged over the two- and three-month lag, to the corresponding residential price of electricity. Row 5: $RelPrice$ is constructed as the ratio of the annual residential price of natural gas in the US to the corresponding residential price of electricity. Row 6: The regression is weighted by the county population in 2000. Row 7: The sample excludes months between December 2007 and June 2009, inclusive. This is the period of the Great Recession as defined by the NBER Business Cycle Dating Committee. Row 8: The specification additionally includes the log of total LIHEAP assistance funds per capita in the state-fiscal year. Row 9: The specification additionally includes the AQIs of carbon monoxide, ozone, and sulfur dioxide as control variables. All other definitions not noted are as in columns 2, 7, and 8 of Table 2 respectively.

Appendix Table A9: Effect of heating price on mortality: Robustness to excluding control variables

	Dependent variable: Log of all-EWM-causes mortality rate		
	Difference-in-differences	Triple difference using winter	Triple difference using HDD
	(1)	(2)	(3)
Exclude housing price index	0.064*** [0.019]	0.074*** [0.019]	0.086*** [0.031]
Exclude unemployment rate	0.055** [0.021]	0.072*** [0.019]	0.083*** [0.031]
Exclude manufacturing share	0.055** [0.021]	0.072*** [0.019]	0.084*** [0.031]
Exclude $\text{Log}(\text{Income}) \times \text{Log}(\text{RelPrice})$	0.039* [0.022]	0.066*** [0.019]	0.075** [0.031]
Exclude $\text{Share70+} \times \text{Log}(\text{RelPrice})$	0.057** [0.021]	0.072*** [0.020]	0.083*** [0.031]
Exclude all pollution controls	0.060*** [0.021]	0.075*** [0.019]	0.084*** [0.031]
Exclude $\text{Share70+} \times \text{Log}(\text{RelPrice})$ and $\text{Log}(\text{Income}) \times \text{Log}(\text{RelPrice})$	0.043* [0.023]	0.068*** [0.020]	0.075** [0.031]
Exclude unemployment rate, manufacturing share, and housing price index	0.060*** [0.019]	0.073*** [0.019]	0.085*** [0.031]

Notes: Each cell shows the result from a separate regression, and reports the coefficient on $\text{ShareGas} \times \log(\text{RelPrice})$ (column 1), $\text{ShareGas} \times \log(\text{RelPrice}) \times \text{Winter}$ (column 2), or $\text{ShareGas} \times \log(\text{RelPrice}) \times \text{HDD}$ (column 3). The corresponding standard error, clustered by state, is shown in brackets. Asterisks denote significance: * $p < .10$, ** $p < .05$, *** $p < .01$. Each row shows a change in specification compared to columns 2, 7, and 8 of Table 2, specifically the exclusion of the control variable(s) indicated in the first column and, where applicable, two-way and three-way interactions that include that variable. All other definitions not noted are as in columns 2, 7, and 8 of Table 2 respectively.

Appendix Table A10: Triple difference mortality estimates using alternative outcomes and specifications

	Dependent variable: Log of mortality rate			
	All causes	All EWM causes	Group I EWM: Circulatory system diseases	Group J EWM: Respiratory system diseases
	(1)	(2)	(3)	(4)
<i>Panel A: Triple difference using winter.</i>				
ShareGas $\times$ Log(RelPrice)	-0.011 [0.0098]	-0.013 [0.015]	0.0093 [0.019]	-0.0080 [0.021]
ShareGas $\times$ Log(RelPrice) $\times$ Winter	0.042** [0.016]	0.073*** [0.019]	0.045** [0.021]	0.11*** [0.028]
<i>Panel B: Triple difference using HDD.</i>				
ShareGas $\times$ Log(RelPrice)	0.046* [0.026]	0.080** [0.039]	0.089** [0.042]	0.079* [0.040]
ShareGas $\times$ Log(RelPrice) $\times$ HDD	0.042* [0.024]	0.084*** [0.031]	0.060* [0.035]	0.10** [0.039]
<i>Panel C: Without controlling in parallel for average winter HDD.</i>				
ShareGas $\times$ Log(RelPrice)	-0.0063 [0.011]	-0.0052 [0.018]	0.016 [0.022]	0.0010 [0.021]
ShareGas $\times$ Log(RelPrice) $\times$ HDD	0.037* [0.021]	0.055* [0.028]	0.030 [0.032]	0.078** [0.037]
Observations	367,905	366,668	362,930	353,692
Mean mortality rate	872.6	527.8	343.5	232.7

Notes: Standard errors clustered by state in brackets. Asterisks denote significance: * $p < .10$, ** $p < .05$, *** $p < .01$. The sample comprises county-year-months in the contiguous U.S. between 2000 and 2010. Mortality rates are age-adjusted mortality rates expressed as annual deaths per 100,000 population; see data appendix for further details. *ShareGas* is the proportion of occupied housing units in the county in 2000 with natural gas as their main heating source. *Log(RelPrice)* is the log of the ratio of the monthly citygate price of natural gas in the US, averaged over the three- and four-month lag, to the corresponding residential price of electricity. *HDD* is the number of heating degree-days in the county for the month, based on thresholds of 65°F, in units of °F-days divided by 1000, and scaled to a 30-day month. All columns in panels A and B include the covariates from columns 7 and 8 respectively of Table 2. Panel C excludes from this set of control variables the two-way and three-way interactions based on the county's average HDD in winter months.

B Data appendix

Appendix Table B1 lists the data source for each of our outcome and independent variables. The following sections provide further description of our data sources and the construction of variables used in this paper.

B.1 Mortality rate

B.1.1 Data source

The data source for mortality is Vital Statistics records, specifically restricted-use “mortality files with all county geographical information” obtained from the National Center for Health Statistics (NCHS). These mortality files include a record for every death certificate filed in the United States during the study period. Each record includes a single underlying cause of death, up to twenty additional multiple causes, month of death, and demographic data, including the deceased’s age, gender, race, Hispanic origin, education, county of residence and county of death. The definition of the underlying cause of death follows that of the World Health Organization (WHO): the disease or injury which initiated the train of events leading directly to death, or the circumstances of the accident or violence which produced the fatal injury. Causes of death are classified using the Tenth Revision of the International Classification of Disease (ICD-10) during the 2000 to 2010 study period.

We compute mortality rates by county, classifying individuals by their county of residence. We restrict our analyses to the contiguous US throughout the paper. We account for substantial county boundary changes by aggregating counties to a larger stable unit.¹³ Specifically, we combine Adams, Broomfield, Boulder, Jefferson, and Weld counties in Colorado; Prince George’s and Montgomery in Maryland; Craven and Carteret in North Carolina; Franklin and Gulf in Florida; Bedford and Bedford City in Virginia; Alleghany and Clifton Forge in Virginia; Augusta and Waynesboro in Virginia; Prince William and Manassas Park in Virginia; Southampton and Franklin in Virginia; and York and Newport News in Virginia.

In addition, when analyzing county-level data, we exclude counties whose population aged 50 and over in 2000 are in the lowest decile of the full sample to reduce noise from mortality rates of counties with small population and missing observations when we use the logarithm of the mortality rate.

B.1.2 Calculating age-adjusted mortality rate

To calculate mortality rates, we use population data from the National Cancer Institutes’s Surveillance Epidemiology and End Results (Cancer-SEER) program. These data give yearly county population estimates by age group, sex, race, and Hispanic origin.¹⁴ For 2005, we use the SEER’s adjusted set of population estimates that takes into account population shifts due to Hurricanes Katrina and Rita.

We use these population estimates to calculate both crude and age-adjusted mortality rates, expressed per 100,000 population. The crude mortality rate at county-year-month level is the total number of deaths in that county in that year-month divided by its population estimate in that year. The age-adjusted mortality rate is a weighted average of the crude

¹³Information on substantial county boundary changes was taken from the Census Bureau’s website.

¹⁴We use vintage 2014 population estimates. The data and documentation are available at <https://seer.cancer.gov/popdata/>.

mortality rates across age categories, where the shares of each age category in the whole U.S. population are used as weights.¹⁵ We use the age distribution of US population in 2000 (the “U.S. 2000 standard population”) published by SEER as weights in the calculation of age-adjusted mortality rates. All mortality rates in the paper are expressed on an annual basis obtained by multiplying the month-level mortality rates by (365/number of day in that month).

B.1.3 Selection of causes of deaths

We use a data-driven approach to select causes of deaths that exhibit significant “excess winter mortality” (EWM), or higher mortality in winter months than in other months.

We use the NCHS’s 113 Selected Causes of Death, which represent groupings of detailed ICD-10 codes, as the mutually exclusive set of causes of death. To measure the degree of EWM for each cause, we construct an observation for each month in the 2000 to 2010 period (132 observations) and calculate the total deaths in the US, by cause, in that month. For each cause separately, we run a regression of the number of deaths due to that cause (i.e., as the underlying cause of death) on a *Winter* dummy, which equals 1 for November to March, and year fixed effects. A similar set of regressions is estimated with the logarithm of deaths as the outcome instead of the level. We then select causes whose *Winter* coefficient is in the top quartile among all causes of deaths in both levels and logs (i.e., above 0.12 for logs and 0.02 for levels). We use both levels and logs of mortality because we want to select causes that are both common and have a strong degree of excess winter mortality.

We exclude two causes from the data-driven list of excess winter mortality causes: first, *Accidental exposure to smoke, fire and flames*, since accidental deaths that are not a physiological result of exposure cold differ from our focus, and second, *All other diseases* (the residual category), since it is difficult to verify the mechanism for this “cause.” Appendix Table A1 reports *Winter* coefficients in levels and logs and average monthly crude mortality rate for each of the selected causes. The final selected list includes the following fourteen causes of death, with their ICD-10 codes in brackets. These causes can be further grouped into four broader cause groups.

- **Group A:** Non-viral, non-respiratory infections
 - Septicemia (A40-A41)
- **Group G:** Neurological diseases
 - Parkinson’s disease (G20-G21)
 - Alzheimer’s disease (G30)
- **Group I:** Circulatory system diseases
 - Acute myocardial infarction (I21-I22)
 - All other forms of chronic ischemic heart disease (I20, I25.1-I25.9)
 - Heart failure (I50)

¹⁵We use the following 19 age categories: under 1 year, 1-4 years, 5-9 years, ..., 80-84 years, and 85 years and over.

- Cerebrovascular diseases (I60-I69)
- Atherosclerosis (I70)
- **Group J: Respiratory system diseases**
 - Influenza (J09-J11)
 - Pneumonia (J12-J18)
 - Emphysema (J43)
 - Other chronic lower respiratory diseases (J44, J47)
 - Pneumonitis due to solids and liquids (J69)
 - Other diseases of respiratory system (J00-J06, J30-J39, J67, J70-J98)

B.2 Home energy price and usage

All energy prices and consumption data come from monthly series published by the U.S. Energy Information Administration (EIA), available at the state and national level. The data are based on samples of firms supplying natural gas or electricity to residential consumers, and include some processing by the EIA to account for non-response.¹⁶

The raw data express quantities in kilowatt-hours for electricity and cubic feet for natural gas. To allow comparison between energy types, we convert these quantities to British Thermal Units (BTU). The conversion is straightforward for electricity. For natural gas, we apply estimates of the heat content of natural gas delivered to residential consumers for each state and year using the company-level data available in the EIA’s Natural Gas Annual Respondent Query System. For these estimates, we drop firms reporting heat content values of 0 or above 2,500 BTU per cubic feet, and weight the reported heat content for each firm by the volume of gas supplied to residential consumers.¹⁷ We also apply two manual edits. First, five state-year observations are missing residential consumer heat content data for all firms; we use the all-consumers heat content for these five observations. Second, the dominant firm in Arkansas is missing heat content data for 2001; we use the average of its report in 2000 and 2002 instead.

Lastly, to aid interpretation of monetary units, we deflate all prices in this paper—including the prices of natural gas and of electricity—to 2016 prices using the Bureau of Labor Statistics’s (BLS) Consumer Price Index (CPI-U).

B.3 Home energy bills

For data on energy bills, we use Census 2000 5-Percent Public Use Microdata Sample (PUMS) files combined with the 2005 to 2010 American Community Survey (ACS) PUMS files. The Census/ACS data are available on an annual basis, and the finest geographic identifier is the Public Use Microdata Area (PUMA). We aggregate the microdata to obtain mean monthly energy bill for each PUMA for the year 2000 and 2005-2010. The relevant question in the Census 2000 is “What are the annual costs of utilities and fuels for this house, apartment, or mobile home?”, broken down into different types of utilities and fuels.

¹⁶Response to the survey is required by law, and hence such non-response should not be a large problem.

¹⁷Heat contents typically range between 900 and 1,200 BTU per cubic feet.

In the ACS, households are asked how much these bills cost them last month (for electricity and gas) and last 12 months (for other fuels). We exclude households whose energy bills are included in their rent or condominium fees.

B.4 Home heating sources (*ShareGas*)

Our identification strategy uses cross-sectional variation in heating sources across geographic areas, represented by the variable *ShareGas*, the proportion of occupied housing units in each state, county, or PUMA in 2000 that indicates that gas is their main heating source. Gas refers to both utility gas from underground pipes serving the neighborhoods and bottled, tank or LP gas. The data source for *ShareGas* at the state and county level is the 2000 Decennial Census of Population and Housing Summary Files, which provide aggregate data at each of the aforementioned geographic levels.¹⁸ The relevant Census question from which *ShareGas* is derived is “Which fuel is used most for heating this house, apartment, or mobile home?” We account for substantial county boundary changes by aggregating counties to a larger stable unit, as described in the mortality data section. *ShareGas* of the larger stable unit is the weighted average of *ShareGas* of each county that makes up the unit, with the weights being the county’s share of total population in 2000 of the larger unit.¹⁹

The data source for *ShareGas* at the PUMA level is the Census 2000 5-Percent PUMS files. Our sample consists of occupied housing units and excludes group quarters and vacant units. We aggregate information at the household level to obtain the proportion of housing units in each PUMA that indicates that gas is their main heating source. We account for the change in PUMA definition due to Hurricane Katrina by aggregating three PUMAs in Louisiana into one stable unit across our sample period²⁰.

B.5 Relative price of natural gas to electricity (*RelPrice*)

Another key variable in our analysis is $\log(\textit{RelPrice})$, the log of the relative price of natural gas to electricity in the US. We use the same data described in Section B.2 for this. The electricity price for the denominator is the national counterpart of that described previously: the national monthly price of electricity supplied to residential consumers.

One candidate for the natural gas price is the national monthly price of natural gas delivered to residential consumers, which is computed by dividing the reported revenue of local distribution utilities by the associated sales volume. The relevant survey question that the EIA uses defines revenue as “gross revenues including any and all demand charges, commodity charges, taxes, surcharges, adjustments or other charges billed for gas delivered”; consequently, fixed charges that utilities frequently include (e.g. basic monthly customer charges that do not depend on volumes) are included. However, we expect consumers to respond to the variable (i.e., usage-dependent) component of prices, not the fixed charge component. In the data, since the fixed charges are averaged over a smaller volume in summer, the residential price spikes in summer (Appendix Figure B1).

Because of this, we use the national monthly price of natural gas at the citygate instead. The citygate price is the price faced by local distribution utilities (companies that sell gas

¹⁸Table H40 of Summary Files 3. Available at American FactFinder (<https://factfinder.census.gov>)

¹⁹County population data come from the 2000 Census of Population and Housing Summary File 1.

²⁰The Census Bureau merged 3 PUMAs (Louisiana 01801, 01802, and 01905) into 1 PUMA (77777) for 2006 and later

to residential consumers); hence it captures variation due to natural gas prices and excludes fixed charges to residents. In addition, utilities are required by federal law to price gas on a cost-recovery basis.²¹ This means that absent forecast errors by the utilities, citygate prices should capture the variation in gas price perfectly. With forecast errors, utilities are legally required to return unexpected profits or losses made on natural gas to consumers by adjusting the future months' prices downwards or upwards. Citygate prices are not available for electricity.

When looking at annual outcomes in the Census/ACS data, we use the annual versions of the price variables. These are based on a separate survey of the universe of firms in the US, but are otherwise identical to the monthly versions.

B.6 Heating degree-days

To compute the number of heating degree-days (HDD), we use daily gridded temperature data for the contiguous US (4 kilometers by 4 kilometers resolution) from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) data developed and maintained by the PRISM Climate Group at Oregon State University (PRISM Climate Group 2004).²² The PRISM data incorporate the current knowledge of U.S. spatial climate patterns, including elevation and prevailing wind patterns, and are the official spatial climate datasets of the U.S. Department of Agriculture (Daly et al. 2008).

To obtain HDD for each county-month, we first compute the geographic average daily mean temperature of each Census 2000 block group. For each block group, we take a simple average of all grid points within, or on the boundary of, the block group. We then compute HDD for each month for each block group, based on

$$HDD_{it} = \sum_{x=1}^{T(t)} \max \{ threshold - tmean_{ix}, 0 \} \quad (3)$$

where HDD_{it} is the HDD of block group i in month t , $threshold$ is a temperature threshold (set at 65°F, following convention), $tmean_{ix}$ is the mean temperature of block group i on day x , and $T(t)$ is the number of days in month t . Next, we compute each county's HDD for the month by taking the average of the block groups within the county, weighted by the population in Census 2000. Finally, we scale HDD to a 30-day month, and divide by 1,000, to yield an average monthly measure of coldness. Block group geographic and population data come from the National Historical Geographic Information System (NHGIS; Manson et al. 2017).

B.7 Median household income and population share age 70+

Data for county and state median household income and fraction of people age 70 and above are from the 2000 Decennial Census of Population and Housing Summary Files. Data at the PUMA level are from the Census 2000 5-Percent PUMS files. Both variables are derived from the Census using the same approach as described above for *ShareGas*.

²¹Note that they may still charge a markup on distribution of gas, which is more difficult for the state to monitor.

²²The specific dataset used is version D1 of the AN81d dataset, retrieved February 2017, from <http://prism.oregonstate.edu>.

B.8 House price index

State house price index used in the paper is the quarterly seasonally-adjusted purchase-only house price index, available from the Federal Housing Finance Agency (FHFA).

B.9 Unemployment rate

We use the Bureau of Labor Statistics' county-month unemployment rate as a control variable. A few county-level observations are missing due to Hurricane Katrina; we use the state unemployment rate for these observations, and include a dummy for affected observations in regressions. When analyzing the Census/ACS, we compute PUMA unemployment rate directly from the microdata.

B.10 Manufacturing share of the economy

We use the Bureau of Economic Analysis's state-quarter personal income data when controlling for manufacturing share of total employee compensation (meant to proxy for share of the economy). A few observations (fewer than 0.5%) are missing; we impute these observations by interpolation. Quarterly data are then matched to the appropriate time period.

B.11 Air pollution data

The data source for air pollution is daily station-level data from the US Environmental Protection Agency (EPA) Air Quality System (AQS).²³ The AQS data contain daily air quality indices (AQIs) for carbon monoxide, nitrogen dioxide, ozone, particulate matter (2.5 and 10), and sulfur dioxide; data for some pollutants for some stations are missing. We construct monthly AQIs for each geographic unit of analysis, and then aggregate to the appropriate time period.

To construct monthly AQIs for each county in our sample for analysis of mortality data, we use a mix of procedures. For the first procedure, we compute each pollutant's AQI at the Census 2000 block group level, and then aggregate to the county level, weighting by population. We compute the AQI for each block group as the average of all AQI measurements taken within a month at all stations within 100 kilometers, weighted by the inverse of the squared distance to the station. County AQI is then the population-weighted average of block group AQIs. Block group and population data come from the NHGIS.

The above procedure (setting a distance threshold and computing the AQI) is standard in the literature using stations data, but it produces many missing observations. We patch missing data using a second procedure. Specifically, if a county has more than 50 percent of its population not assigned a pollutant AQI value in any month, we use a second procedure to compute its AQI values for all months. For these counties, for each month, we compute AQI based on the nearest five stations with available measurements, weighted by the inverse of the squared distance between the station and the county centroid. This guarantees that all counties have a pollution AQI measure for all months in consideration.

Appendix Table B2 shows, for each pollutant, the breakdown of the procedure used to compute AQI in the sample of counties used in our analysis of mortality data.

²³The EPA provides several ways of accessing the data. We use the pre-generated data files, accessed February 2017.

We construct monthly AQIs at the PUMA or state level for use in analyzing the other outcome variables analogously. We then aggregate to the relevant time period for analysis. This differs depending on the outcome variable. When looking at the effects on home energy price, usage, and mortality, we aggregate to the monthly level directly. When looking at the effects on home energy bills, we additionally account for the time structure in the ACS. ACS documentation indicates that around half of data for each month are collected two months prior through computer-assisted personal interviewing, and around half are collected contemporaneously through mail or the internet. In addition, we account for possible lags in bill payment. For this, we assume that two-thirds of interviewees in a certain month report the bill paid in the previous month, and one-third report the bill paid two months ago (because the most recent bill might not have been paid yet). Hence, when aggregating monthly AQIs for a particular year when analyzing the Census/ACS, we include data from up to four previous months (September the previous year gets one-sixth of a month's worth of weight, etc.).

B.12 Independent variables used in heterogeneity analysis

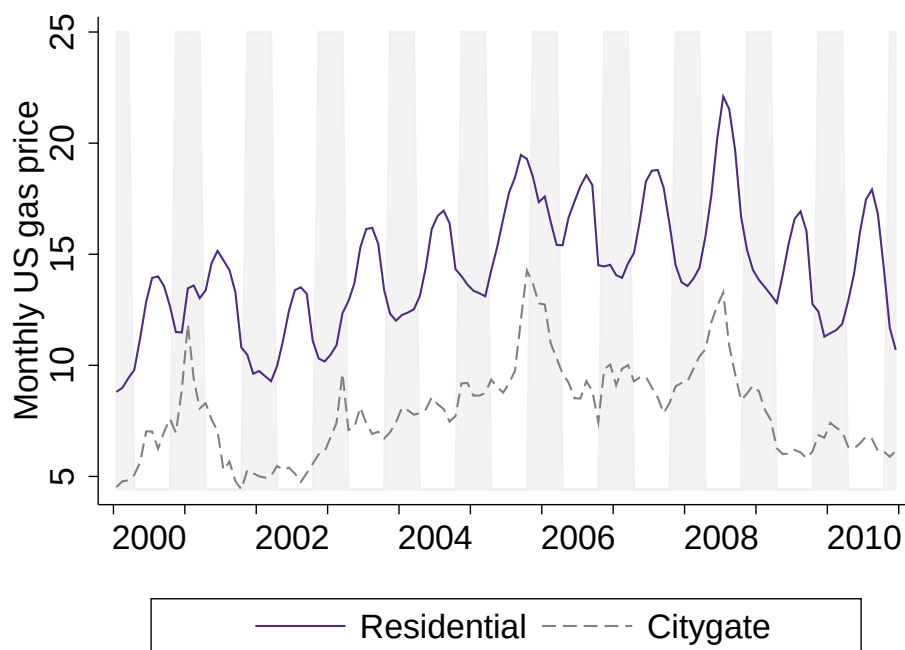
Variables used in analysis of heterogeneity in the effect of heating price on mortality are from the following sources:

- **Poverty rate:** Data on proportion of households in the county with income below 150% of the poverty level is from the 2000 Decennial Census of Population and Housing Summary Files.
- **Education:** Data on the deceased's education level is provided in the mortality files. We drop deaths that occur before the age of 25, with censored education level, for this analysis. To compute age-adjusted mortality rates by education level, we use Census/ACS population data, since the SEER data does not contain a breakdown by education level. We interpolate proportions for the years in which no population data exist (2001 to 2004).
- **Sex:** Data on the deceased's sex is provided in the mortality files.

B.13 LIHEAP data

As a robustness check, we use data on Low Income Home Energy Assistance Program (LIHEAP) spending from the U.S. Department of Health and Human Services' LIHEAP Data Warehouse. The data are based on mandatory reports from states for each fiscal year, and are available at the state-fiscal year level starting in fiscal year 2001 (i.e. since October 2000). For the nine months in our sample without LIHEAP data, we impute an arbitrary value for LIHEAP per capita and include a dummy for affected observations in the regressions.

Appendix Figure B1: National price of natural gas over time



Notes: Price in dollars per million BTU. Gray regions are winter months (November–March).

Appendix Table B1: Data sources

Data	Data source	Geographic identifier	Temporal identifier
Dependent variables			
Mortality rate	Vital Statistics Mortality Files	County	Month
Average home energy price	Energy Information Administration (EIA)	State	Month
Home energy usage	Energy Information Administration	State	Month
Home energy bill	Census; American Community Survey (ACS)	PUMA	Year
Independent variables			
Home heating energy type	Census	Census tract	Year
Energy prices	Energy Information Administration	State	Month
Temperature	PRISM	Grid point ^a	Day
Median household income	Census	Census tract	Year
Fraction of people aged 70 & above	Census	Census tract	Year
House price index	Federal Housing Finance Agency	State	Quarter
Air pollution	Environ. Protection Agency Air Quality System	Pollution monitor	Day
Unemployment rate	Bureau of Labor Statistics	County	Month
Manufacturing share of economy	Bureau of Economic Analysis	State	Quarter
LIHEAP assistance funds	Department of Health and Human Services	State	Fiscal year

^a 4 km by 4 km resolution

Appendix Table B2: Frequency of the two interpolation procedures used for calculating AQIs

	CO	NO ₂	O ₃	PM _{2.5}	PM ₁₀	SO ₂
Based on distance threshold	1,177	1,048	1,096	2,231	1,762	1,512
Based on nearest 5 stations	1,616	1,745	1,697	562	1,031	1,281
Total counties	2,793	2,793	2,793	2,793	2,793	2,793

Climate Change and Energy Insecurity: A Growing Need for Policy Intervention

Michelle Graff,¹ David M. Konisky, Sanya Carley, and Trevor Memmott

ABSTRACT

Energy insecurity, or a household's inability to afford its basic energy needs, is an under-appreciated material hardship that millions of low-income U.S. households face every month. When households experience energy insecurity, they are more likely to take financial risks, engage in unsafe coping strategies, as well as suffer adverse mental and physical impacts as they try to pay their energy bills and avoid utility disconnection. In this commentary, we share new survey data that identify the energy insecure population in the United States, revealing that Black and Hispanic households are more likely to experience this material hardship than white households. We argue that climate change will likely deepen this problem due to ongoing and projected increases in average and extreme temperatures, which will expose those that cannot afford to maintain comfortable temperatures inside their homes to extreme heat. This exposure may lead to severe health consequences, including heat exhaustion and death from heatstroke. We maintain that current policies and programs are insufficient to mitigate climate-induced energy insecurity and conclude by offering several policy recommendations that state and federal policymakers should consider as the effects of climate change mount and adversely affect energy insecure communities.

Keywords: energy insecurity, climate change, racial disparities, policy recommendations

INTRODUCTION

EVERY MONTH, MILLIONS of U.S. households face decisions about which expenses they can afford, and which they cannot. People are often forced to decide whether they should pay their rent or mortgage, feed their family, or

seek medical care.¹ A widespread, but under-appreciated, concern that many households experience is their (in)ability to afford their basic energy needs, a concept that has been defined as “energy (in)security.”² Energy insecurity not only places a financial burden on millions of Americans, but it can also lead households to engage in unsafe behavior (e.g., using stoves or space heaters, which are the leading causes of domestic home fires and related deaths³) and pursue risky financial decisions (e.g., taking out high-interest payday loans⁴). In some circumstances, energy insecurity is

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¹Jayanta Bhattacharya, Thomas DeLeire, Steven Haider, and Janet Currie. “Heat or Eat? Cold-Weather Shocks and Nutrition in Poor American Families.” *American Journal of Public Health* 93, (2003): 1149–1154.

²Diana Hernández. “Understanding ‘Energy Insecurity’ and Why It Matters to Health.” *Social Science & Medicine* 167 (2016): 1–10.

³Richard B. Campbell. *Home Fires Involving Heating Equipment*. Quincy, Massachusetts: National Fire Protection Association, 2016.

⁴Rob Levy and Joshua Sledge. “A Complex Portrait: An Examination of Small-Dollar Credit Consumers.” Chicago, Illinois: *Center for Financial Services Innovation, Report*, 2012.

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also associated with mental (e.g., stress, disrupted sleep, and depression²) and physical health impacts (e.g., asthma, upper respiratory infections, and premature death).^{5,6,7}

The concept of energy insecurity is related to energy justice,⁸ which argues that policymakers should ensure that everyone has access to safe, reliable, affordable, sustainable, and modern energy.⁹ When a household is energy insecure, it lacks either affordable and/or reliable energy. Other related concepts to energy insecurity are energy burden—or the proportion of income spent on energy—and energy poverty, both of which have been studied extensively in European contexts.^{10,11} Unlike in the United States, the U.K. government has differentiated energy poverty from general poverty,^{12,13} considering a household energy poor if their energy costs are above the national median and if the household spent an amount on energy, such that their remaining income would place them below the poverty line.¹⁴

Climate change is likely to exacerbate household energy insecurity. Higher incidence of extreme temperatures will place further burdens on those experiencing energy insecurity and may force other households to confront it as well. With much of the United States expected to experience more days of extreme heat,¹⁵ the

problem of energy insecurity will deepen. Building resiliency to address these impacts requires a rethinking of current programs and policies to ensure that vulnerable households, especially communities of color and low-income populations who have higher residential energy usage,¹⁶ more often live in dilapidated or inefficient housing,¹⁷ and experience higher rates of energy insecurity,¹⁸ are actively considered and cared for.

In this commentary, we share new survey data revealing that household energy insecurity is already widespread among low-income U.S. households and argue that climate change will likely worsen this material hardship. We posit that current state-level policies and federal-level programs are insufficient to alleviate or protect vulnerable communities from climate-induced energy insecurity. For these reasons, we recommend that state governments broaden disconnection protections and moratoria to all vulnerable groups and focus on expanding these protections to better cover the hot summer months. At the federal level, Congress should provide additional funding for both bill assistance and weatherization programs; however, they should prioritize efforts to escalate the weatherization of low-income homes to reduce household carbon emissions and the cost of energy bills, thus providing a longer-term solution for vulnerable households.¹⁹

HOUSEHOLD ENERGY INSECURITY IN THE UNITED STATES

Household energy insecurity is a prevalent problem in the United States. Every four years, the U.S. Energy Information Administration administers the Residential Energy Consumption Survey, which asks Americans about their energy use and bills. According to the 2015 survey, the most recent version available, ~14 million households had unpaid energy utility bills, 17 million households received a disconnection notice from their utility provider, and 2 million households had their electricity service disconnected by their utility.²⁰

The survey research reported in the article was approved by the Indiana University Office of Research

⁵Edmond D. Shenassa, Constantine Daskalakis, Allison Liebhaber, Matthias Braubach, and MaryJean Brown. "Dampness and Mold in the Home and Depression: An Examination of Mold-Related Illness and Perceived Control of One's Home as Possible Depression Pathways." *American Journal of Public Health* 97, (2007): 1893–1899.

⁶Mark J. Mendell, Anna G. Mirer, Kerry Cheung, My Tong, and Jeroen Douwes. "Respiratory and Allergic Health Effects of Dampness, Mold, and Dampness-Related Agents: A Review of the Epidemiologic Evidence." *Environmental Health Perspectives* 119, (2011): 748–756.

⁷Tony G. Reames, Dorothy M. Daley, and John C. Pierce. "Exploring the Nexus of Energy Burden, Social Capital, and Environmental Quality in Shaping Health in US Counties." *International Journal of Environmental Research and Public Health* 18, (2021): 620.

⁸Darren A. McCauley, Raphael J. Heffron, Hannes Stephan, and Kirsten Jenkins. "Advancing Energy Justice: The Triumvirate of Tenets." *International Energy Law Review* 32, (2013): 107–110.

⁹Kirsten Jenkins, Darren McCauley, Raphael Heffron, Hannes Stephan, and Robert Rehner. "Energy Justice: A Conceptual Review." *Energy Research & Social Science* 11 (2016): 174–182.

¹⁰Lucie Middlemiss and Ross Gillard. "Fuel Poverty from the Bottom-Up: Characterising Household Energy Vulnerability Through the Lived Experience of the Fuel Poor." *Energy Research & Social Science* 6 (2015): 146–154.

¹¹Benjamin K. Sovacool. "Fuel Poverty, Affordability, and Energy Justice in England: Policy Insights from the Warm Front Program." *Energy* 93 (2015): 361–371.

¹²Dominic J. Bednar and Tony G. Reames. "Recognition of and Response to Energy Poverty in the United States." *Nature Energy* 5, (2020): 432–439.

¹³B. Boardman. *Fuel Poverty: From Cold Homes to Affordable Warmth*. (Pinter Pub Limited., 1991).

¹⁴Department for Business, Energy & Industrial Strategy. Fuel Poverty Statistics. GOV.UK. Last updated June 25, 2020. <<https://www.gov.uk/government/collections/fuel-poverty-statistics>>. (Last accessed on February 1, 2021).

¹⁵Erik Romanowsky, Dörthe Handorf, Ralf Jaiser, Ingo Wohltmann, Wolfgang Dorn, Jinro Ukita, Judah Cohen, Klaus Dethloff, and Markus Rex. "The Role of Stratospheric Ozone for Arctic-Midlatitude Linkages." *Scientific Reports* 9, (2019): 1–7.

¹⁶Tony Gerard Reames. "Targeting Energy Justice: Exploring Spatial, Racial/Ethnic and Socioeconomic Disparities in Urban Residential Heating Energy Efficiency." *Energy Policy* 97 (2016): 549–558.

¹⁷Diana Hernández, Douglas Phillips, and Eva Laura Siegel. "Exploring the Housing and Household Energy Pathways to Stress: A Mixed Methods Study." *International Journal of Environmental Research and Public Health* 13, (2016): 916.

¹⁸Trevor Memmott, Sanya Carley, Michelle Graff, and David M. Konisky. "Sociodemographic Disparities in Energy Insecurity among Low-Income Households Before and During the COVID-19 Pandemic." *Nature Energy* 6, (2021): 186–193.

¹⁹Bruce Tonn, Beth Hawkins, Erin Rose, and Michaela Marincic. "Income, Housing and Health: Poverty in the United States Through the Prism of Residential Energy Efficiency Programs." *Energy Research & Social Science* 73 (2021): 101945.

²⁰U.S. Energy Information Administration (EIA). "2015 Residential Energy Consumption Survey." (2018).

Compliance, under protocol number 2004296209. In accordance with this protocol, informed consent was provided by all study participants. Recent survey data collected by the authors further elucidate the extent of household energy insecurity in the United States among low-income Americans.²³ As part of a nationally representative survey fielded in May 2020 to ~2,000 households with incomes at or below 200% of the federal poverty line, we found that nearly 4.7 million households (or about 24 million individuals) could not pay an energy bill in at least one month of the previous year. In addition, 4.8 million households received a disconnection notice from their utility, and ~2 million households lost service due to nonpayment.¹¹

During the early months of the coronavirus disease pandemic, we found even higher rates of energy insecurity. Between April/May 2020 and August 2020, 21% of respondents (representing ~3.8 million low-income households) indicated that there was at least one month during this period in which their household could not afford to pay their bill; 15% of respondents (representing about 2.8 million households) indicated that they had received a disconnection notice, and 6% (representing about 1.2 million households) noted that they had their service shutoff.²¹

Past research has identified race- and income-based disparities in household energy insecurity,^{22,23,24} and we find similar results, even among low-income households. As shown in Figure 1, between April/May and August 2020, Black and Hispanic households were about twice as likely as white households to be unable to pay an energy bill. Moreover, Black and Hispanic households were, respectively, two and three times more likely to receive a disconnection notice and three and eight times more likely to be disconnected from the electric grid due to lack of payment.

CLIMATE CHANGE WILL EXACERBATE ENERGY INSECURITY

According to the most recent National Climate Assessment, the average U.S. temperature is projected to rise by at least 2.5 degrees Fahrenheit by 2050 as a direct result of increases in greenhouse gas concentrations.²⁵ In addition,

researchers predict that the United States will experience 20–30 more days over 90 degrees Fahrenheit by 2050, with increases of ~40–50 days in the Southeast.²⁶ Although this increase in average and daily temperature extremes will contribute to fewer cold spells (6 days with minimum temperatures below the 10th percentile), especially in Alaska and the Northeast, it will result in more severe and frequent heat waves (6 days with maximum temperatures above the 90th percentile), particularly in the Southeast, Southwest, and Alaska.

Studies reveal that domestic heat waves are already occurring more often than in previous decades due to climate change, especially in cities. In the 2010s, metropolitan areas averaged six heat waves per year, an increase from the 1960s average of two times per year.²⁷ In 2020, many cities endured long stretches of record-breaking heat due to the urban heat island effect—when highly urbanized areas endure higher temperatures as compared with suburban and rural locations because heat is more easily absorbed and emitted by buildings and asphalt.²⁸ For example, Phoenix, Arizona broke several heat-related records in 2020, experiencing more than 145 days above 100 degrees, 15 days above 115 degrees, and ~300 recorded heat-related deaths.²⁹

As highly populated regions of the United States face increasing exposure to extreme heat, we not only expect the energy insecure population to grow but also expect the potential adverse consequences to worsen. Research has documented that exposure to extreme temperatures, especially heat, can compromise the body's ability to regulate its internal temperature.³⁰ Therefore, as temperatures rise, those households with access to air conditioning or fans will face higher energy costs,³¹ whereas other households

²⁶Russell Vose, David R. Easterling, Kenneth Kunkel, and Michael Wehner. "Temperature Changes in the United States." (2017).

²⁷Dana Habeeb, Jason Vargo, and Brian Stone. "Rising Heat Wave Trends in Large US Cities." *Natural Hazards* 76, (2015): 1651–1665.

²⁸L.A. Dupigny-Giroux, E.L. Mccray, M.D. Lemcke-Stampone, G.A. Hodgkins, E.E. Lentz, K.E. Mills, E.D. Lane, R. Miller, D.Y. Hollinger, W.D. Solecki, G.A. Wellenius, P.E. Sheffield, A.B. MacDonald, and C. Caldwell, 2018: Northeast. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [D.R. Reidmiller, C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program. Washington, DC, pp. 669–742.

²⁹Rebecca Hersher and Lauren Sommer. "2020 May Be the Hottest Year on Record. Here's the Damage it Did." *National Public Radio*: (2020). <<https://www.npr.org/2020/12/18/943219856/2020-may-be-the-hottest-year-on-record-heres-the-damage-it-did>>. (Last accessed on February 1, 2021).

³⁰Marcus C. Sarofim, Shubhayu Saha, Michelle D. Hawkins, David M. Mills, Jeremy Hess, Radley Horton, Patrick Kinney, Joel Schwartz, and A. St Juliana. *Ch. 2: Temperature-Related Death and Illness*. (U.S. Global Change Research Program, 2016).

³¹Mo Chen, George A. Ban-Weiss, and Kelly T. Sanders. "Utilizing Smart-Meter Data to Project Impacts of Urban Warming on Residential Electricity Use for Vulnerable Populations in Southern California." *Environmental Research Letters* 15, (2020): 064001.

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²²Ariel Dreobl and Lauren Ross. "Lifting the High Energy Burden in America's Largest Cities: How Energy Efficiency Can Improve Low Income and Underserved Communities." (Washington D.C.: American Council for an Energy-Efficient Economy, 2016).

²³Eva Lyubich. (2020). "The Race Gap in Residential Energy Expenditures." *Energy Institute at HAAS*. <https://assets.ctfassets.net/ntcn17sslow9/6Xj2o8VJUWjKDWh-CzRooKY/00464dbde818d4656101d8c398fcf6dd/The_Race_Gap_in_Residential_Energy_Expenditures.pdf>. (Last accessed on February 1, 2021).

²⁴Diana Hernández, Yumiko Aratani, and Yang Jiang. "Energy Insecurity Among Families with Children." (New York, NY: National Center for Children in Poverty, 2014).

²⁵Donald J. Wuebbles, David W. Fahey, Kathy A. Hibbard, Jeff R. Arnold, Benjamin DeAngelo, Sarah Doherty, David R. Easterling, et al. "Climate Science Special Report: Fourth National Climate Assessment (NCA4), Volume I." (Ames, Iowa: Iowa State University Digital Repository, 2017).

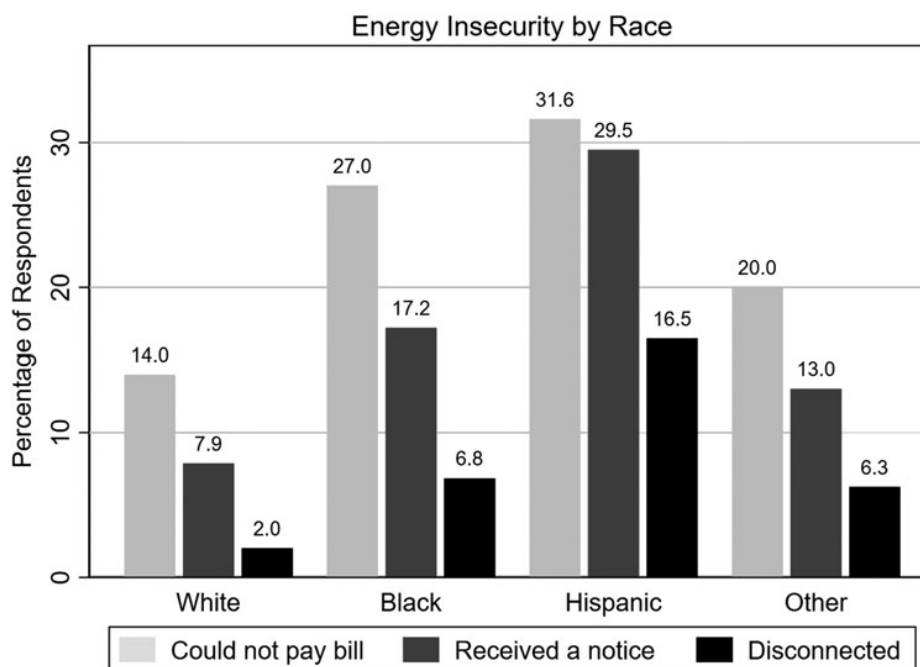


FIG. 1. Energy insecurity by race, between May and August 2020.

that cannot afford larger energy bills may decide to forgo air conditioning or fans to limit their expenses.³² Those households that cannot maintain comfortable temperatures are more likely to experience exposure to extreme heat, which can lead to illness, including heat cramps, heat exhaustion, and heatstroke, and can also aggravate pre-existing conditions, such as cardiovascular, kidney, and respiratory diseases.²⁵ These risks affect energy insecure households, people of color, elderly individuals, those living in public housing, in urban areas, and in homes without air conditioning more often.^{33,34,35,36}

In some circumstances, exposure to extreme heat is also correlated with increased hospital admissions and excess deaths.³⁷ Recent research suggests that we do

not have an accurate estimate of the number of historical weather-related deaths in the United States, especially as it pertains to heatstroke or heat exhaustion.³⁸ According to the Centers for Disease Control and Prevention (CDC), an estimated 65,000 people visit the emergency room for acute heat illnesses annually, with 618 cases of premature mortality documented every year.³⁹ However, the CDC (2016) argues that the number of deaths is underestimated because extreme heat is often not identified by a medical examiner as the primary cause of death, and the estimate is closer to 5,600 each year.⁴⁵

In sum, as the effects of climate change worsen, especially increasing rates of extreme heat events, households that cannot afford to keep their homes at comfortable temperatures as well as those already experiencing material hardships, such as preexisting medical conditions, will likely experience the brunt of domestic energy insecurity and the health consequences will likely be severe.⁴⁰

³²Guy R. Newsham, and Brent G. Bowker. "The Effect of Utility Time-Varying Pricing and Load Control Strategies on Residential Summer Peak Electricity Use: A Review." *Energy Policy* 38 (2010): 3289–3296.

³³Jeffrey Berko. *Deaths Attributed to Heat, Cold, and Other Weather Events in the United States, 2006–2010*. No. 76. (U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Health Statistics, 2014).

³⁴Grégoire Rey, Anne Fouillet, Pierre Bessemoulin, Philippe Frayssinet, Anne Dufour, Eric Jouglu, and Denis Hémon. "Heat Exposure and Socio-economic Vulnerability as Synergistic Factors in Heat-Wave-Related Mortality." *European Journal of Epidemiology* 24, (2009): 495–502.

³⁵Eric Klinenberg. *Heat Wave: A Social Autopsy of Disaster in Chicago*. (University of Chicago Press, 2015).

³⁶Barry S. Levy and Jonathan A. Patz. "Climate Change, Human Rights, and Social Justice." *Annals of Global Health* 81, (2015): 310–322.

³⁷Abderrezak Bouchama. "The 2003 European Heat Wave." *Intensive Care Medicine* 30, (2004): 1–3.

³⁸Kate R. Weinberger, Daniel Harris, Keith R. Spangler, Antonella Zanobetti, and Gregory A. Wellenius. "Estimating the Number of Excess Deaths Attributable to Heat in 297 United States Counties." *Environmental Epidemiology (Philadelphia, Pa.)* 4, (2020): 1–4.

³⁹Centers for Disease Control and Prevention (CDC). "Climate Change and Extreme Heat." (2016). <<https://www.cdc.gov/climateandhealth/pubs/extreme-heat-guidebook.pdf>>. (Last accessed on February 1, 2021).

⁴⁰Kristina Dahl, Rachel Licker, John T. Abatzoglou, and Juan Declet-Barreto. "Increased Frequency of and Population Exposure to Extreme Heat Index Days in the United States During the 21st Century." *Environmental Research Communications* 1, (2019): 075002.

POLICY DISCUSSION

To address the growing issue of energy insecurity, federal and state government officials need to consider policies that address the scope of the problem and that better align with the mounting health risks posed by climate change. Currently, there is no federal policy that protects vulnerable customers from utility disconnections. State governments have enacted policies, but these vary considerably in design and reach, and collectively provide only a patchwork of protection.^{41,42}

State disconnection protections fall into four general categories: vulnerable populations, procedures regarding notification, financial considerations, and extreme temperatures.⁴³ Regarding vulnerable populations, all but a handful of states limit the shutoff of energy services (usually electricity and natural gas) for customers with medical conditions; whereas protection for low-income populations, elderly customers, households with young children, or people with disabilities is less common. Importantly, the burden of documenting eligibility for these protections generally falls on the customer. Moreover, state policies vary in the type of notification (e.g., written, telephone, in-person) that they require of utilities before discontinuing services as well as in provisions that may require utilities to offer payment plans for customers in arrears before ending their service.

Of most relevance for this commentary, states have adopted two common approaches with respect to extreme temperatures: (1) date-based, such that utilities are limited from disconnecting customers during certain times of the year; and (2) temperature-based, which impose similar restrictions on disconnections when temperatures are above or below a defined threshold. In some instances, these protections apply to all users, whereas in others they are limited to specific groups (e.g., low-income, elderly). Importantly, as illustrated in Figure 2, 44 states have cold weather-related protections, whereas just 16 have protections for hot weather.

Given expectations of more excessive heat due to climate change, these policies are not aligned with future risks of heat-related illness and mortality.^{44,45} This is a

major shortcoming of existing protections that states should rectify immediately.

Moreover, the two federal programs that aim at alleviating energy insecurity—the Low Income Home Energy Assistance Program (LIHEAP) and the Weatherization Assistance Program (WAP)—are historically underfunded. The WAP, which aims at reducing energy costs for low-income households through energy efficiency upgrades, only serves 35,000 households each year.⁴⁶ LIHEAP, which helps low-income households pay their energy bills, can only provide bill assistance for ~22% of the income-eligible population.⁴⁷ LIHEAP funds are so limited that they tend to focus on helping people pay for their heating rather than cooling needs because they are often exhausted by the spring and summer months.⁵¹ In sum, current levels of government assistance are inadequate and electricity disconnection protection across the country is uneven, which leaves millions of Americans in potentially precarious circumstances.⁴⁸

POLICY RECOMMENDATIONS

Without policy interventions to help U.S. households improve their home's energy efficiency, pay their utility bills, and protect them from utility disconnections, millions of vulnerable Americans will face severe risks to their health and well-being as the effects of climate change intensify. There are several steps that government officials can take, in the near and long term, to improve the policies and programs aimed at helping energy insecure households withstand or adapt, recover from, and be resilient to rising residential energy costs, declining economic security, and increasing climate change-induced threats.

In the near term, the federal government should provide additional funding to both LIHEAP and WAP. Appropriating more funds to LIHEAP would help customers with near-term concerns, such as paying their energy bills, avoiding disconnection, and relieving debt accrual. Importantly, providing more funding to bill assistance could allow state program offices to remain open through the hot summer months and help low-income households cool their homes and fix or replace broken air-conditioning equipment. Simultaneously, the federal government should also prioritize funding WAP to help households achieve longer-term goals, including improving deficient housing stock, reducing energy use and carbon emissions, and increasing energy bill affordability. Funding WAP at higher levels could

⁴¹M. Franklin, C. Kurtz, M. Alksnis, L. Steichen, and C. Younger. "Lights Out in the Cold: Reforming Utility: Shut-Off Policies as If Human Rights Matter." *National Association for the Advancement of Colored People* (2017): 1–71.

⁴²Matthew Flaherty, Sanya Carley, and David M. Konisky. "Electric Utility Disconnection Policy and Vulnerable Populations." *The Electricity Journal* 33, (2020): 106859.

⁴³Disconnection protection policies only apply to the utilities regulated by public utility commissions, which often only includes investor-owned utilities, leaving most customers served by electric cooperatives and municipal utilities unprotected or subject to utility-specific policies.

⁴⁴Jennifer F. Bobb, Roger D. Peng, Michelle L. Bell, and Francesca Dominici. "Heat-Related Mortality and Adaptation to Heat in the United States." *Environmental Health Perspectives* 122 (2014): 811–816.

⁴⁵David Mills, Joel Schwartz, Mihye Lee, Marcus Sarofim, Russell Jones, Megan Lawson, Michael Duckworth, and Leland Deck. "Climate Change Impacts on Extreme Temperature Mortality in Select Metropolitan Areas in the United States." *Climatic Change* 131 (2015): 83–95.

⁴⁶Department of Energy. Action, Weatherization In. "Weatherization Works!." <<https://nascsp.org/wp-content/uploads/2020/01/WAP-Fact-Sheet-2019.pdf>>. (Last accessed on February 1, 2021).

⁴⁷Libby Perl. *LIHEAP: Program and Funding*. (Library of Congress, Congressional Research Service, 2015).

⁴⁸The third COVID relief package enacted by Congress—the American Rescue Plan Act of 2021—included \$4.5 billion in new funding for the LIHEAP program.

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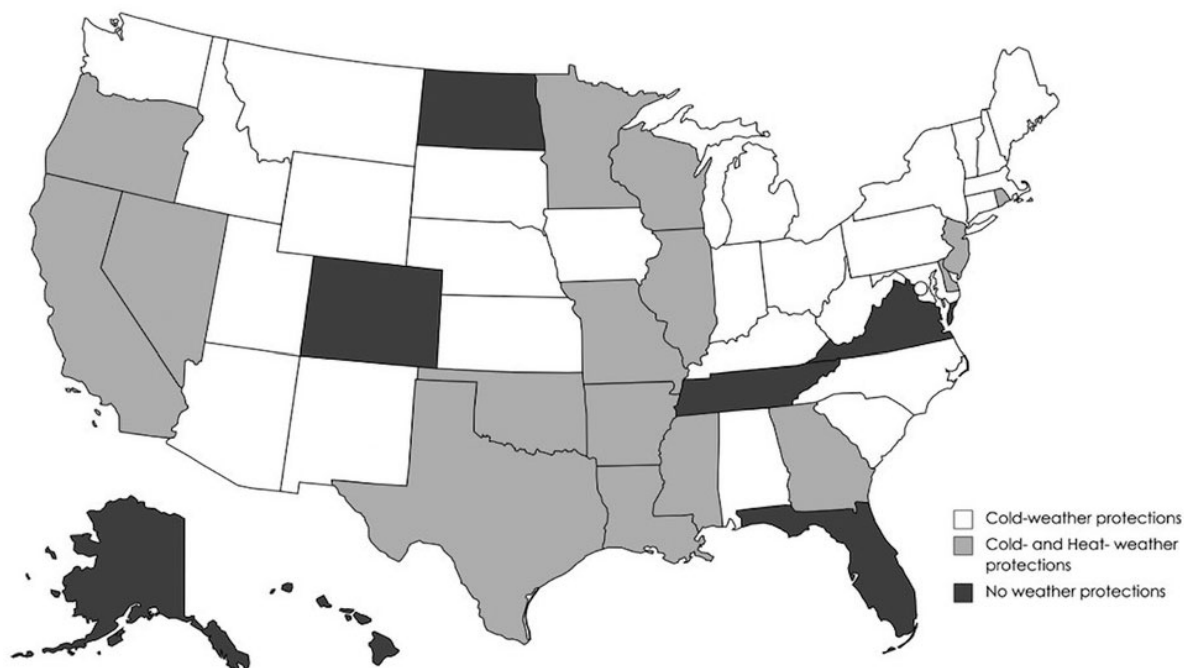


FIG. 2. Map of Weather-Related Disconnection Protections. *Source:* Data was collected using regulatory and legal code from all 50 states and Washington, D.C.

alleviate strains on LIHEAP and other bill assistance programs and may also translate to the availability of more local energy efficiency jobs. In addition, the federal government should not only appropriate higher levels of funding for both the LIHEAP and WAP programs every year, but they should also (1) coordinate efforts across programs to improve efficiency and implementation of both programs; (2) target the most vulnerable populations in the United States^{49,50}; and (3) when possible, reduce hurdles that applicants face to gain access to both LIHEAP and WAP⁵¹ as well as allow local agencies the flexibility to implement these programs to meet their specific community's needs.⁵²

In the long term, state governments should carefully reconsider their current disconnection policies and make reforms to broaden their coverage and to reduce the administrative burdens that households need to overcome

to meet eligibility requirements. For example, all states should consider implementing date-based, in addition to temperature-based, protection so as to standardize and simplify these policies for customers. States should also consider indefinite and absolute protection for certain groups, including those who require the use of an electronic medical device. In particular, it is critical that these reforms cover all low-income households and types of utilities so that protection is not contingent on where one lives or who their energy is provided by. In anticipation of rising temperatures because of climate change, most states need to update their policies so that they include heat-related protection. For most parts of the country, climate change will bring more days with excessive heat, and utility disconnection policies should reflect these changing circumstances.

When determining how to improve household energy and climate resiliency, federal and state governments as well as electric utilities must consider energy insecurity as a tangible material hardship that low-income families face and therefore an important aspect of general household and societal health and well-being.⁵³ Once they do, federal and state governments should work together with public utility commissions and electric utilities to strategically generate and implement a comprehensive set of programs and policy interventions to help households experiencing energy insecurity. Building

⁴⁹Dominic J. Bednar, and Tony G. Reames. "Recognition of and Response to Energy Poverty in the United States." *Nature Energy* 5 (2020): 432–439.

⁵⁰Tony Reames. "Improving the Effectiveness of Federal Energy Assistance for Low-Income Households." *Scholar Strategies Network* (2017).

⁵¹Pamela Herd and Donald P. Moynihan. *Administrative Burden: Policymaking by Other Means*. (Russell Sage Foundation, 2019).

⁵²Shiva Raissi, and Tony G. Reames. "If We Had a Little More Flexibility." Perceptions of Programmatic Challenges and Opportunities Implementing Government-Funded low-Income Energy Efficiency Programs." *Energy Policy* 147 (2020): 111880.

⁵³Jeremiah Bohr and Anna C. McCreery. "Do Energy Burdens Contribute to Economic Poverty in the United States? A Panel Analysis." *Social Forces* 99 (2020): 155–177.

resiliency to the effects of climate change requires addressing the unequal impacts that it will bring, including the increasing costs of energy that are likely to result.

As federal, state, and local governments address the problem of energy insecurity, they may find more traction if they address it through a coordinated approach that considers its inter-related challenges with housing, education, and health. Energy insecurity is a complex problem that involves more than just whether a household has enough money to pay its energy bill; it correlates with housing options and conditions, employment opportunities, and mental and physical health, among other important dimensions. Therefore, a comprehensive approach that addresses a range of personal and structural challenges faced by vulnerable households is most likely to generate durable outcomes. Such efforts have the potential to help households build resiliency to the looming and growing threats of climate change.

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Energy, Poverty, and Health in Climate Change: A Comprehensive Review of an Emerging Literature

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Household energy is increasingly vital for maintaining good health. Unaffordable and inadequate household energy presents adverse consequences that are amplified by poverty and a changing climate. To date, the connections between energy, socioeconomic disadvantage, and well-being are generally underappreciated, and household energy connection with climate change is under-researched. Building on the energy insecurity framework, this review explores literature related to household energy, poverty, and health in order to highlight the disproportionate burdens borne by vulnerable populations in adequately meeting household energy needs. This paper is based on a comprehensive review of books, peer-reviewed articles, and reports published between 1990 and 2019, identified via databases including JSTOR and PubMed. A total of 406 publications were selected as having potential for full review, 203 received full review, and 162 were included in this paper on the basis of set inclusion criteria. From the literature review, we created an original heuristic model that describes energy insecurity as either acute or chronic, and we further explore the mediators and pathways that link energy insecurity to health. In the discussion, we posit that the extant literature does not sufficiently consider that vulnerable communities often experience energy insecurity bundled with other hardships. We also discuss energy, poverty, and health through the lens of climate change, making the criticism that most research on household energy does not consider climate change. This evidence is important for enhancing research in this field and developing programmatic and policy interventions as they pertain to energy access, affordability, and health, with special emphasis on vulnerable populations, climate change, and social inequality.

Keywords: energy insecurity, climate change, vulnerable populations, housing, health

INTRODUCTION

Global energy demand and consumption have increased substantially and are expected to continue rising (1); this is particularly evident in countries with strong economic growth such as China and India (2). The U.S. Energy Information Administration (EIA) has predicted that world energy use will increase by 28% by 2040 (2). In 2017 alone, global energy demand rose 2.1%—twice as much as in 2016 (3). As climate change worsens, the demand for more energy services and the strain on existing services will increase. As of 2017, residential energy consumption accounted for 20% of

the total energy consumption across all sectors in the U.S. (4). Ensuring affordability, access, and adequate production of household energy is vital for maintaining individual and population-scale health and well-being. Household energy uses include cooking, lighting, heating, cooling, cleaning, and technological, medical, and other life-sustaining devices (5–7). Yet, millions of households around the world live without an adequate amount of energy (8).

Adequate access to energy is encumbered by limited and faulty infrastructure, affordability challenges, and service disruptions due to disasters and extreme weather events, often linked to climate change. This phenomenon, known as energy insecurity, is defined as the “inability to adequately meet household energy needs” (9). The energy insecurity framework includes physical, economic, and behavioral dimensions that lead to or exacerbate adverse health issues (9). The physical dimension includes poor housing quality, the structure of the home environment, and inefficient appliances (9). The economic dimension consists of affordability challenges (though it is not based merely on an economic ratio or threshold), while the behavioral dimension focuses on coping strategies, social vulnerabilities, and indicators of resilience (9). This conceptual framework helps us to understand the phenomenon of energy insecurity and its consequences. This framework parallels that of food insecurity—the “disruption of food intake or eating patterns because of lack of money and other resources” (10)—in that it reflects cost, quality, and health impacts.

In this article, we present the results of our review of the existing literature on energy insecurity and demonstrate the range of concerns and of approaches to resolving them. We propose the new terms—“acute” and “chronic” energy insecurity to further understand and break down household energy issues. Our findings suggest that the literature does not sufficiently consider the intersectionality of vulnerability types and multiple hardships. Furthermore, the use of numerous terms for household energy insecurity further compartmentalizes energy issues by geography and discipline, hampering the possibility for a comprehensive, or systematic literature base. This compartmentalization foregoes the opportunity to address energy insecurity as a complex, interdisciplinary, intersectional, and multidimensional issue, especially in the context of the pressing threat of climate change. For the sake of clarity, we provide below a brief overview of terms currently used to describe household energy issues as they relate to socioeconomic disadvantage, and in some cases, health.

HOUSEHOLD ENERGY TERMINOLOGY

Many different terms have been used to describe the demand side of energy-related hardship. Researchers, policymakers, and practitioners have popularized terms such as fuel poverty, energy burden, energy vulnerability, and energy poverty, among others. These terms differ in their geographic usage and somewhat in their methods of measurement, but all similarly reference issues related to energy consumption and affordability. Energy burden and fuel poverty are mirroring terms that are used separately in different geographic regions; the former in the

U.S. and the latter mostly in the United Kingdom (U.K.), Ireland, and New Zealand. Both terms are generally defined by an economic ratio whereby households that allocate more than 10% of their gross income for indoor energy expenses are considered energy burdened or fuel poor (9, 11–13). Energy poverty is generally attributed to the Global South and refers to the lack of modern energy services and low energy consumption (5, 14–20). Outcomes and indicators of energy poverty center on socioeconomic development, well-being, and poverty (21). A newer term, energy vulnerability, was developed to bridge the geographical research gap between fuel poverty and energy poverty in order to shed light on energy hardship as a global problem (14, 21). Importantly, these terms and their definitions have not yet incorporated the uncertain realities of climate change and its impact on energy, even though climate impacts are fundamentally rooted in how energy is produced and consumed, and its availability is threatened by the aftermath of extreme weather events, often caused by climate change.

Despite evidence of a strong association between energy access, affordability, and health, none of the above terms inherently focus on health. Research and policy tend to focus on the economic factors of energy burden, fuel poverty, and energy vulnerability, leading to financially-motivated interventions. For example, household-level financial subsidies (e.g., bill assistance) are a popular intervention, as opposed to more structural measures such as energy efficiency upgrades or adoption of clean energy technologies. Moreover, such an economic focus does not address the full scope of the problem, as it leaves out psychosocial and behavioral factors, among others, that contribute to energy hardship. Even energy poverty’s focus on well-being and socioeconomic development omits housing quality and affordability constraints as a focus. By comparison, energy insecurity more broadly encompasses a wider spectrum of energy-related hardships that may be internal or external to an individual’s experience of the phenomenon and is attuned to an expansive range of socioeconomic, psychological, and environmental determinants that produce energy-related hardship. The energy insecurity framework offers the opportunity to evaluate health predictors and outcomes in the context of climate change (22).

The present review provides an encompassing account of the relationship between energy, health, poverty, and climate change and the pathways by which these factors are interlinked. We address the critical gap in the importance of energy for population health (15, 23) by focusing not only on medical issues but also on the cycles of social disadvantage implicated in the nexus of energy, health, and poverty. We outline the impacts of global climate change on household energy access and how it contributes to the severity of health effects and discuss the need to accommodate growing demand on energy systems. This review provides evidence that health is a necessary consideration amidst increases in global energy demand. This is particularly important when: (1) developing methods for energy efficiency and production; (2) deciphering how to distribute and provide energy to low-income, marginalized, and vulnerable households equitably; and (3) preparing for climate change and acute threats to energy access.

PAPER ORGANIZATION

We begin our analysis with a heuristic model linking the various factors that emerged during the review process, including the phenomena of chronic and acute energy insecurity (see **Figure 2**). This paper is organized into four thematic sections with subthemes. First, we propose new terminology to describe different manifestations of energy insecurity. Second, we review the evidence on energy insecurity and the social determinants of health by discussing the social patterning of energy insecurity by gender, age, health status, education, employment, socioeconomic status, and race. Next, we review evidence on the association between energy insecurity and place, noting the spatial inequalities in neighborhood resources and demographics that contribute to the increased likelihood that some community members will experience energy insecurity. Third, we outline findings regarding the connection between energy insecurity, housing quality, and home energy infrastructure by exploring the relationships between housing tenure, energy efficiency, and home age. Fourth, we highlight the salience of coping strategies and behaviors enacted by households experiencing energy insecurity and describe the health effects of temperature extremes, high-effort coping, and the depletion of resilience reserves. The *resilience reserve* is a framework that describes how resilience that should be preserved for use in a specific event, such as in response to a natural disaster, becomes depleted due to constant use in response to a greater prevalence of chronic daily struggles (24). To conclude, we summarize the findings of our review and describe the cumulative hardships of energy insecurity. In the discussion, we offer a critical analysis of the literature, highlighting that the research does not adequately consider the intersectionality of experiences of energy insecurity, infrequently employs an environmental justice framework, and lacks cohesive terminology. These critiques are discussed in relation to the growing wealth gap, increasing energy costs and demand, research into household energy in the Global South, and the inevitable impact of climate change.

METHODS

This review is based on a comprehensive search for relevant literature published between 1990 and 2018 and archived in JSTOR and PubMed. The literature review conceptually frames energy issues along the lines of climate change, health, and socioeconomic factors. The literature review search was conducted using a matrix of terms in varying combinations with one another. The search terms and their categories are outlined in **Table 1**. Terms from each category were searched along with terms from other categories. For example: (1) [(energy insecurity) AND (poverty) AND (climate change) AND (health)]; and then, (2) [(fuel poverty) AND (poverty) AND (climate change) AND (health)]. A term from the “Social,” “Health,” and “Energy” category was used in every search because one of our inclusion criteria is that articles discuss the relationship between household energy, health, and socioeconomic status. We did not include “climate change” as a required term for every search, as part of the review is analyzing the extent to

which the existing literature on household energy considers climate change. We excluded sources about energy and climate change that did not have a health outcome or a socioeconomic focus. Any source that did not discuss energy at the household, neighborhood, or community level was also excluded. Beyond this, our criteria were purposefully broad in order to capture the breadth of topics related to household energy use, health, and climate.

The search was limited to articles in English. Books, peer-reviewed articles, and reports were included, and all other source types were excluded. Our initial database search plus additional articles added from reviewing the reference sections of various sources yielded 750 results. After discarding duplicate sources and literature that was not relevant based on title, we had 406 sources. These sources underwent title and abstract screening. At this point, we identified 203 sources for full review. Of these, 162 were analyzed and incorporated into the final manuscript (**Figure 1**). Some sources out of the 203 identified were not included in the final manuscript due to the subsequent irrelevance of their topic once the topics discussed in the manuscript had been refined during editing.

HEURISTIC MODEL

Energy insecurity can impact health in a multitude of ways. Studies on energy insecurity encompass not only direct but also indirect health impacts because they consider social determinants of health and the coping strategies people use in response to energy insecurity. Inadequate household energy has been linked to the following health outcomes for both adults and children: cardiovascular, pulmonary, and respiratory illnesses; cancer; arthritis; acute hospitalization; excess mortality in summer and winter; and anxiety, depression, and stress (9, 13, 22, 25). Indirect health impacts, such as food insecurity, are also associated with energy insecurity (6, 26–30). It is important to highlight how indirect health problems contribute to and compound direct health impacts related to household energy insecurity. With health as an endpoint, our innovative, original heuristic model (**Figure 2**) tracks the multifaceted pathways that directly and indirectly link energy insecurity to health by distinguishing between chronic and acute energy insecurity.

DEFINING CHRONIC AND ACUTE FORMS OF ENERGY INSECURITY

Energy insecurity is a complicated, multifaceted issue that may be best understood by parsing out its various forms—acute and chronic energy insecurity. For this reason, we propose the incorporation of these terms into the lexicon of energy insecurity work. *Chronic energy insecurity* is a long-term issue that can arise from a consistent inability to afford or access adequate energy to meet household needs. An example of chronic energy insecurity would be living in a home that is consistently cold because the cost of heating is unaffordable. The lack of adequate household energy is often predicated on a number of social and demographic factors including age, gender, socioeconomic

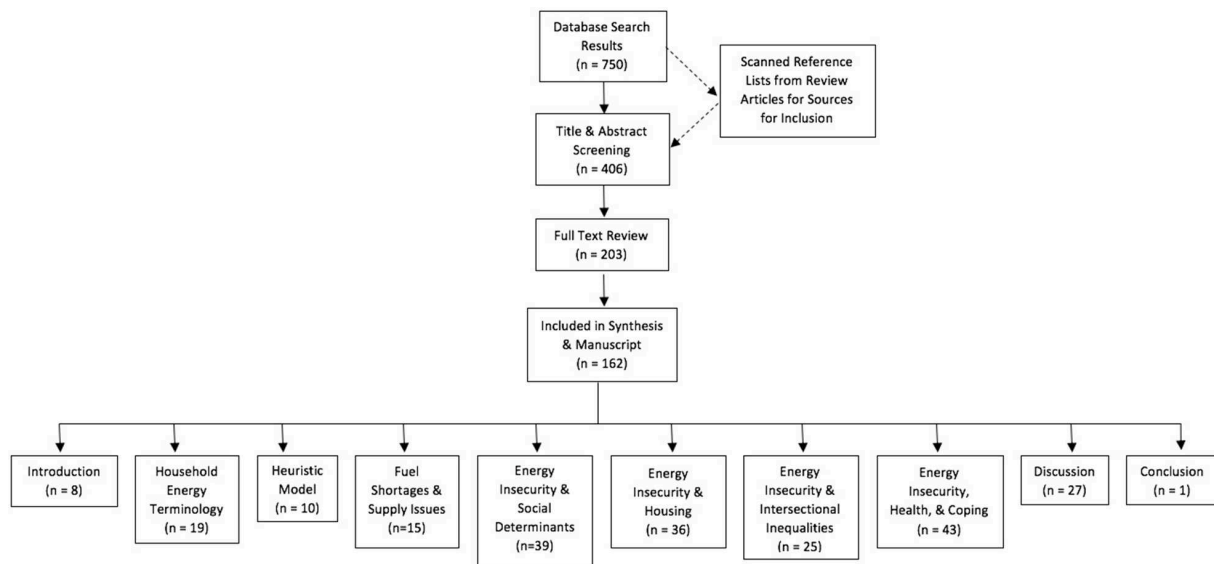


FIGURE 1 | Flow chart of literature selection and review process.

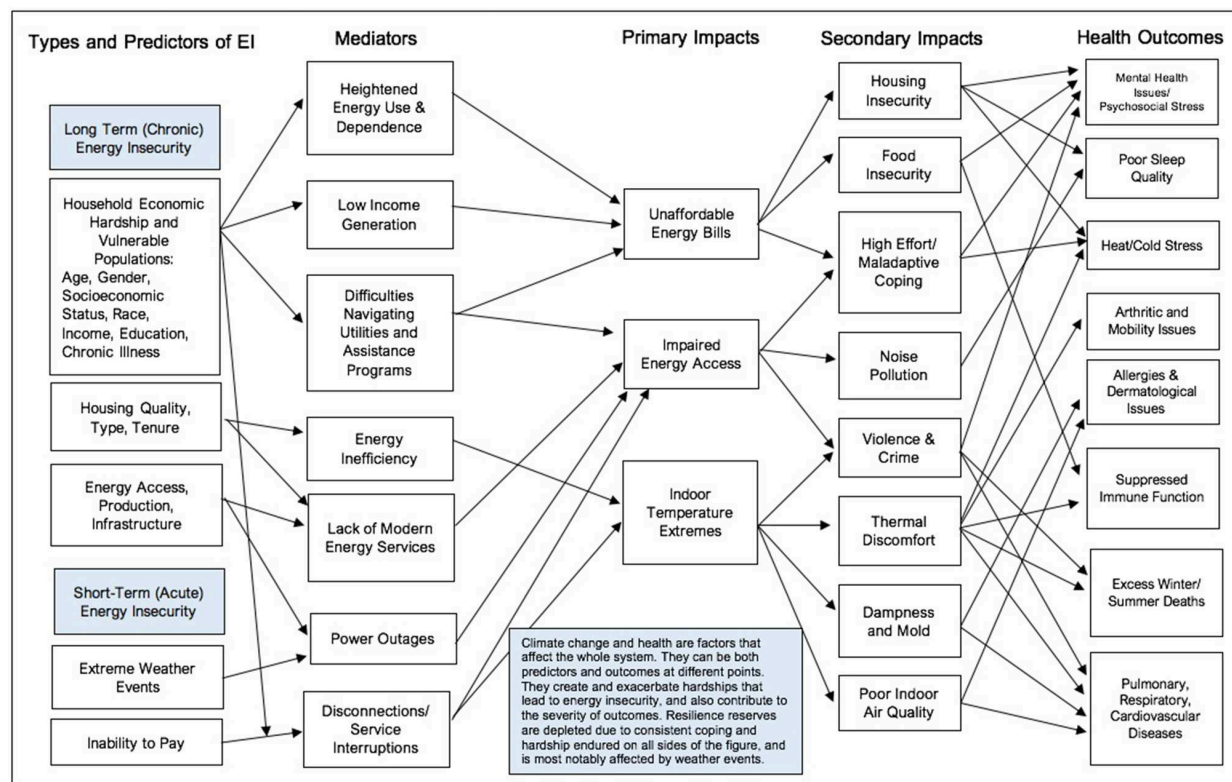


FIGURE 2 | Connection between household energy insecurity (EI) and health.

TABLE 1 | Search terms used in the literature review.

ENERGY TERMS
• Fuel poverty • Energy poverty • Energy burden • Energy vulnerability • Energy insecurity • Energy inefficiency
HEALTH TERMS
• Health • Chronic illness or conditions • Excess winter mortality, excess heat death
HOUSEHOLD TERMS
• Household, Housing, or Home • Neighborhood or Community
SOCIAL TERMS
• Low-income • Poverty • Socioeconomic Status • Vulnerable population • Social vulnerability • Resilience • Coping • Housing/Food insecurity
CLIMATE TERMS
• Natural disaster • Extreme Weather event • Climate change • Global warming • Heat wave • Hurricane • Power outage or shutoff

status, education, income, race, and employment status. These characteristics may have implications for earnings potential, can determine a household's ability to navigate available resources, and affect access to efficient housing and energy use patterns.

Acute energy insecurity is a short-term issue that tends to arise from infrastructural, maintenance, environmental, or other external sources that disrupt access to energy sources. Some examples of acute energy insecurity include a power outage from a hurricane or a gas shutoff from a reported leak. Interestingly, chronic energy insecurity can lead to a significant crisis point of acute energy insecurity, such as shut-offs due to non-payment. Shutoffs are an acute form of energy insecurity because, for the most part, they are short-lived, and services are reinstated upon cost recovery by the energy service provider. Three primary forms of acute energy insecurity—fuel shortages and supply issues, power outages, and shut-offs—and the links between service interruptions and ill health are described next.

FUEL SHORTAGES AND SUPPLY ISSUES

Health impacts from energy access issues (when infrastructure is available) can arise when demand exceeds supply via two

primary routes: (1) fuel shortages and (2) capacity of the energy infrastructure to handle excess demand during extreme weather. Fuel shortages across the world also indirectly impact health by increasing fuel cost and making sources unaffordable, leading to inaccessibility. Sometimes, other resources necessary for life are contingent on energy access. For example, during a fuel shortage, rural Iñupiaq Eskimo villages in Alaska's Northwest Arctic Borough were unable to access clean water because they did not have heat or electricity to prevent pipes from freezing (31). The shortage led to increased rates of infectious disease, hygiene-related diseases, and pneumonia (31). Fuel shortages may become worse as climate change worsens, increasing the prevalence of health issues related to energy insecurity (32).

In other instances, the energy infrastructure has proven incapable of tolerating higher than normal demands. A polar vortex, which occurred in January 2019 across the United States, brought extremely cold temperatures that strained energy systems. Some parts of the Midwest reached temperatures as low as minus 38 degrees Fahrenheit (33). An estimated 21 people died across the country from causes directly related to the polar vortex, such as death by hypothermia while indoors (34). One woman in Milwaukee died from the cold when her thermostat malfunctioned (34). In many cities, gas companies ordered households and industry to lower their heat in order to prevent citywide gas shortages (33). This compromised capacity is related to reliance on an aging infrastructure and increased demand, which is likely to be an issue over time and as weather patterns become more extreme as a result of climate change.

Power Outages

Infrastructural issues, extreme weather, and natural disasters may result in power outages and energy service interruptions. Short-term power outages often occur for the following reasons: (1) older and less reliable infrastructure; (2) overloading from high electricity demand; (3) household maintenance defects; and/or, (4) other systems fail (35). Long-term power outages are typically a result of disasters such as hurricanes. In 2017, Hurricane Maria left Puerto Rico's residents without power for an unprecedented average of 84 days. An estimated 83% of these households were in the most remote regions of Puerto Rico (36). These outages interrupted healthcare for people with chronic illnesses who required care and medication (36). Moreover, the death toll attributable to Hurricane Maria in Puerto Rico was estimated to be 4,645 people, and 9.5% of those deaths were due to an inability to access electricity needed for respiratory equipment (36). The adverse impacts of service interruptions—both short- and long-term—are ubiquitous. Elevator shutdowns impede movement, transit systems close, medical device access can be cut off, blackouts can increase crime and cause accidents, food can spoil in warming refrigerators, temperature control can be lost, and much more (35, 37–39).

Shutoffs

Affordability challenges may lead to a different type of service interruption—shutoffs or disconnections due to non-payment. It is challenging to measure a national prevalence rate of shutoffs, because utility companies seldom, if ever, report which and

how many households are shut off, and these data are generally not publicly available. Hernández and Laird (40) used the Residential Energy Consumption Survey (RECS), administered by the Energy Information Administration (EIA), to analyze the prevalence of disconnection notices and service disconnections based on a nationally representative sample of US households. Hernández and Laird (40), presenting their results at the annual conferences of the American Sociological Association (ASA) and the American Public Health Association (APHA), demonstrated that in 2015 an estimated 3% of US households were disconnected and another 15% received a disconnection notice, suggesting that there is indeed some hardship. Consistent with previously observed patterns of inequality, the authors also found that low-income households, African-American and Latino households, households with children, renters, and people living in older and poorly insulated homes were most likely to receive disconnection notices and service interruptions. Hernández and Laird's (40) research further explores the coping strategies that families resort to, such as forgoing food and medicine and keeping homes at an unhealthy temperature, that compromise health and may even lead to death. Hernández and Laird (40) found that households rely on these strategies to prevent and respond to the threat and occurrence of shutoffs (40).

Service Interruptions and Health

Shutoffs and power outages have a number of direct health impacts (30, 35, 37). Temperature-related issues such as hypothermia and heat stress increase when interruptions occur at times of extreme outdoor temperature. Chronic health conditions are strained by short- and long-term service interruptions in electricity and hot water services (30, 41). Additionally, people with chronic illnesses, particularly those with cardiovascular, respiratory, and renal diseases, are often forced to seek outside medical care during interruptions, increasing the rate of hospitalization (35, 42). Rates of all-cause and external-cause mortality are significantly higher during power-outage periods, especially when outages are due to weather events such as hurricanes, heatwaves, and snowstorms (30, 35). Households that have faced threats of shutoffs have reported more long-term mental health issues stemming from financial, physical, and environmental stress, as well as fears and anxiety over potential future service interruptions (13, 43).

ENERGY INSECURITY AND SOCIAL DETERMINANTS

Both acute and chronic energy insecurity are influenced by the social determinants of health, which are defined by the Centers for Disease Control and Prevention (CDC) as the political, economic, and social circumstances in which people live, work, and play (44). These determinants include factors such as gender, age, health status, education, employment, socioeconomic status, and race. Here, we review literature indicating that the social determinants of health play an important role in predicting the existence of household energy difficulties and outline the importance of making a connection between the impact of

climate change on social determinants of health and energy insecurity. As climate change increases the frequency, duration, and magnitude of extreme weather events, it is important to consider the populations that are most vulnerable to the impacts of such events within the context of household energy use (45, 46).

Age and Life Course Vulnerability

Age-related vulnerabilities (i.e., being young or elderly) and exposure to environmental hazards are predictors of energy insecurity. The elderly, because they are at a higher risk of experiencing medical events during heatwaves than other populations due to a combination of social isolation, heightened physiological vulnerability, and the likelihood of not having air conditioning, are more likely to endure heat stress (46–48). Children are at risk of asthma, especially those living in urban, low-income communities, and are therefore in more need of adequate energy for ventilation and temperature control (49–51). Both the elderly and children spend more time in their home environments than other groups (1), increasing their exposure to the health risks of energy insecurity (52).

Education: Literacy and Impacts on Academic Achievement

Education, as it relates to energy insecurity, also has implications for health. Lacking sufficient knowledge and ability to navigate the bureaucracy of utility companies makes it difficult for less-educated households to address and prevent energy insecurity. Knowing how to access resources such as financial subsidies or medical certifications to prevent shutoffs requires knowledge of how such bureaucratic systems work. Understanding the risks associated with using alternative methods to address energy needs also requires education. On average, those with less educational attainment have more limited income potential, making it more difficult to afford and make energy payments (6, 15).

Energy insecurity also perpetuates a cycle of lower educational attainment, most notably for children. Environmental stress and financial insecurity can lead to mental health issues and result in worse educational outcomes (53). The stress of energy hardship is associated with behavioral problems in children, whereby they are more likely to have low academic motivation, difficulty concentrating, and often act out (54, 55). Children experiencing energy insecurity and food insecurity (discussed in detail in subsequent sections) are also more likely to experience intensified behavioral issues such as depression, rule-breaking behavior, and somatic complaints (54). Asthmatic children in energy-insecure households with poor air quality miss more days of school due to illness than do non-asthmatic children (55, 56). Homes that use unsuitable energy sources expose children to toxic gasses that impair cognitive development. Additionally, children living in energy-insecure households often have trouble focusing on their homework due to noise pollution from generators, other loud energy sources, and open windows, which can lead to lower academic success (57). As a coping strategy, some households confine energy use to specific rooms to keep energy bills low or because there are limitations in their heating and cooling systems;

this forces all residents to be in the same room, resulting in homework distractions and crowding, among other issues. Poor or restricted lighting to certain rooms also makes schoolwork and reading for pleasure more challenging.

Employment

Energy insecurity perpetuates the detrimental health effects associated with low-income employment. Many low-paying jobs require work in extreme temperature conditions (58), such as farming in excess heat or working in refrigerated warehouses. Those working in extreme temperature conditions are also more likely to be experiencing energy insecurity at home because they are low-income. Exposure to thermal discomfort at work and at home has a cumulative effect on temperature-sensitive health problems. Members of low-income households are also more likely to work multiple jobs to pay bills and support their families, meaning they are often physically absent from the home. This absence of caretakers can affect children's developmental needs and contribute to social deprivation and caretaker stress. Single mothers are more likely to be primary caretakers and often experience augmented impacts because they do not have a partner with whom they can share the burden and responsibility. Single mothers are also more at risk of experiencing energy insecurity compared to other groups (9, 23).

Socioeconomic Status and Household Income

Socioeconomic factors are a predictor of energy insecurity. In most households, utilities make up a substantial portion of living costs, and in low-income households, this proportion is much greater (9, 30, 59). Therefore, it can be difficult for low-income households to pay for enough energy to meet household needs and also afford other expenses (9, 30). Households at or near the Federal Poverty Level (FPL) are significantly more burdened by energy insecurity than other socioeconomic groups (9). A brief look at 2011 American Community Survey (ACS) data on the characteristics of people experiencing the gap between energy affordability and unaffordability found that 44% of low-income families (defined as below 200% of the FPL) experience economic energy insecurity compared to 2% of families who are not low-income (60). A 2016 report by the American Council for an Energy-Efficient Economy (ACEEE) found that lower-income households experience higher median energy burden (7.2%), defined as the percentage of household income spent on energy bills, whereas non-low-income households experienced a median energy burden of 1.5% (61). Furthermore, a recent study found that low-income households in the studied U.S. cities spend on average from 10 to 20% of their income on energy bills, while wealthier households spend on average between 1.5 to 3 percent on energy bills despite being the higher consumers (59). The 2015 RECS found that the lower the income, the higher the energy expenditure and energy consumption per square foot of the home due to a number of potential factors (62). For example, socioeconomic status has major implications for affordability, access, and levels of environmental hazards in the home. Additionally, low-income households are often unable to afford utility bills and therefore live without adequate energy

due to heightened conservation and/or an inability to upgrade energy-related appliances and systems (59).

Race

Race is another social determinant of health that can predicate energy insecurity. Minorities tend to suffer from higher rates of energy cost burden than non-Hispanic whites in United States' cities (59). In the U.S., African Americans suffer more from energy insecurity than do any other racial groups (23, 60, 63). Of surveyed households with an African-American head of household (HOH) and children under the age of 18, 35% reported facing energy insecurity compared to 21% of Latino HOHs with children under 18 and 14% of Caucasian HOHs with children under 18 (60). Across all income levels, Black families still maintained the highest rates of energy insecurity (60). In the Washington Heights neighborhood in New York City, energy-insecure households were more likely to be black and Hispanic/Latino, low-income, and have less education (64). In Detroit, a study found that African-American households were twice as likely to be behind on utility payments and three times more likely to suffer from arrearage or shut-offs than white households (65).

When considering racial disparities, the association between environmental hazard exposure and geographical location is stronger for Black and Latino communities than for other racial groups (66). The health impacts of energy insecurity are compounded for racial-minority households that live in areas with high rates of exposure to environmental hazards energy inefficiencies (59, 66). The disparity in the impacts of acute energy insecurity is especially apparent for minority racial groups. For example, a study by O'Neill et al. (67) found that during heatwaves in four different cities across the U.S., the rate of air conditioning use was more than two times higher among the white population than the black population, suggesting that black residents did not have access to or could not afford to use air conditioning at the same rate as white residents. Additionally, the mortality rate of black residents was significantly higher than that of other racial groups across all four cities (67). This trend could be attributed to low income levels and unaffordable electricity, which disproportionately impact racial and ethnic minority households.

Gender

Gender is another social factor associated with energy insecurity that has direct and indirect health implications. In the Global South, women and girls, who are responsible for cooking, use biomass fuel, resulting in high rates of respiratory illness. Respiratory illness from solid-fuel cooking is one of the greatest causes of premature mortality globally (5, 7, 15, 68). In the Global North, women are more likely to be caretakers and spend more time at home, increasing their rate of exposure to other energy inefficiencies. Single mothers are especially vulnerable because they take on financial and psychosocial burdens alongside the responsibility of being the sole caretaker (23). It is important to note, however, that the literature in this review often fails to recognize that the separation of how gender relates to energy insecurity in the Global North vs. the Global South is reductive

and essentialized, as all of the mechanisms by which women and girls are impacted by energy issues crosscut both spheres of the world.

Health Status

Illness and chronic health problems often determine energy demand and have implications for energy consumption, thereby making poor health both a predictor and outcome of energy insecurity. Residents with health conditions such as cardiovascular, pulmonary, and respiratory diseases and arthritis are sensitive to temperature extremes, meaning that a home that is too cold or too hot can exacerbate and worsen symptoms (13, 69–71). People living with a chronic health condition may be especially reliant on energy-dependent devices for treatment or maintenance of their condition, lowering their ability to withstand inadequate or unavailable energy services. For example, patients with kidney disease, chronic obstructive pulmonary disease (COPD), and cardiovascular disease (CVD) rely on dialysis and oxygen machines that require electricity (72) and diabetics must refrigerate their insulin. Cancer patients in active treatment need more heat (73), and those suffering from hypertension are more susceptible to cold stress (74). Not only do people with chronic health conditions have an increased need for energy, but they also spend more time in their households, further increasing energy use (75).

ENERGY INSECURITY AND HOUSING

A number of household characteristics beyond location predict the existence of unmet household energy needs. The type of housing, whether owned or rented, its level of energy efficiency, and its age are all associated with energy insecurity. Low-income and minority residents face a higher proportion of difficulties related to these housing characteristics.

Housing Tenure and Type

Energy insecurity is affected by housing tenure because renting and owning can lead to unique challenges that perpetuate energy insecurity. Low-income renters often face difficulties affording household costs (76) and tend to spend the greatest portion of their income on energy bills when compared to other socioeconomic groups (77). They also tend to live in the most structurally deficient homes due to a lack of weatherization and efficiency upgrades (77). Energy insecurity can become a chronic issue, partly because low-income renters have limited ability to persuade landlords to maintain proper upkeep and implement effective modifications related to energy efficiency (43, 78). They also have limited social and economic capital to afford self-repairs or to hold landlords accountable through the court system (43). Low-income owners are also at risk for energy insecurity due to the high cost of upgrading homes to higher efficiency standards or because buying a home that is already efficient is expensive. Homeowners are often responsible for the entire burden of utility bills and other operational costs, including property taxes, home insurance, and water, garbage, and sewer costs. The stress of low-income housing on both renters and owners is associated with adverse mental health outcomes and poor self-rated health (43, 76).

Housing type also influences rates of energy insecurity. Similar to homeowners, renters of single-family units face difficulties because they are responsible for the entire cost burden. Multifamily housing can be more advantageous than single-family housing because there is a shared cost with property owners. However, residents in multifamily housing and low-income tenants often lack control over the conditions (e.g., heat) of their units and have restricted ability to combat energy insecurity, mostly due to financial constraints and lack of control over housing infrastructure (9). The New York City Housing Authority (NYCHA), the country's largest public housing authority, has faced notorious housing quality and energy infrastructure issues that have plagued residents by severely compromising their housing experience and, likely, their physical, and mental health. One challenge is that NYCHA is not subject to the same maintenance regulations as private housing or developers, resulting in structural deficiencies and energy inefficient housing, attributable in part to deferred maintenance (79). Public housing is not alone in this regard. Rental housing, including subsidized, or affordable housing, presents challenges for renters since the property owners determine the level of energy efficiency and other aspects of housing quality. In most cases, there are no guidelines that stipulate a minimum level of efficiency, particularly in older housing that was constructed when building codes were less focused on sustainability. This conundrum, known as the “split incentive,” occurs when the incentive structure for an asset is not equally beneficial to both parties. In such cases, the deciding actor works in their own best interest, as is the case with owners who dictate the terms of housing without consideration of tenancy. Previous research demonstrates that subsidized housing recipients face an increased burden because they are more likely to rent from private landlords who neither weatherize nor optimize energy efficiency due to upfront costs and administrative encumbrances, which generally privileges the property owners and negatively impacts the tenants both economically and experientially (77, 80).

Beyond rental and multiunit housing, people living in manufactured housing, such as trailers or mobile homes, are disproportionately impacted by physical energy insecurity. These housing structures are often not well-insulated or weatherized, so residents tend to spend a high proportion of their income on energy and heating bills. For example, the ACEEE found that mobile home residents are more likely to be energy burdened (61). Residents living in these manufactured housing types also tend to be low-income and therefore the least able to sustain high utility bill costs or afford general maintenance (81).

Energy Inefficiency

Energy inefficiency is a common housing problem and aspect of energy insecurity that has serious health implications. Energy inefficiency is marked by poor insulation, drafts, leaks, and other points of intrusion of the outside elements that make it difficult to control indoor temperatures (82–84). Other structural deficiencies and poor housing quality conditions, such as a lack of central air conditioning and proper ventilation, can also lead to high utility bills and unsafe conditions (85). Energy inefficiency caused by poor housing quality and structural deficiencies

spurs costly utility bills that are unaffordable for low-income people (86). Poor energy efficiency has been associated with an increase in household dampness (85), which is associated with worsened arthritis symptoms, dizziness, headaches, and fevers (79), and increases the presence of mold, exacerbating medical conditions such as allergies, eczema, and asthma (69, 87–90). Energy inefficiency is also associated with an increase in a number of thermal-related illnesses (85), and homes with poor ventilation and outside air infiltration have more dust mites and cockroach feces, which are known to exacerbate or lead to acute respiratory illnesses (27, 91–93). Households that are unable to open windows (see also the section entitled Heat Stress and Forbearance) have the additional risk of dampness as a result of obstructed airflow (57).

A popular intervention for older and/or poorly constructed homes is retrofitting (87). However, energy efficiency without attention to ventilation can lead to excess tightness in the building envelope, thereby obstructing airflow and exacerbating the aforementioned health issues related to ventilation and air quality (94). Air-tightness due to energy efficiency improvements is also associated with increased levels of radon, which significantly increases the risk of lung cancer (95, 96).

Age of Housing

Older housing is a frequent contributor to energy insecurity because much of the aged housing stock around the world is neither weatherized nor energy-efficient, which results in an increased prevalence of thermally inadequate home environments (97). Low-income, older and minority householders are often relegated to substandard living conditions, in part due to residence in older housing that has not been renovated (98). The effect of older, less efficient housing on energy insecurity has been studied mostly in the fuel poverty literature from northern Europe and New Zealand, where the regularity of colder outdoor temperatures heightens the need for consistent indoor heating (82, 99). Excess winter deaths are a measure of mortality as a result of cold homes, a problem known to be caused by a lack of insulation (13, 47, 69, 84, 99–101). Heat stress is a common health effect of hotter outdoor temperatures, whereas newer technology such as centralized air conditioning may not exist in older homes. A lack of air conditioning contributes to heat stress, excess deaths, and hospitalizations during heatwaves (67, 102). Therefore, the use of newer technology is important for health and safety, particularly as it relates to the prevention of premature death.

Newer homes are subject to current housing codes, many of which include public health considerations, and tend to be more energy-efficient and have fewer maintenance issues (97). Many states have ventilation standards, for example, which can combat mold from dampness and therefore reduce asthma symptoms (98). Regulations on toxin levels in homes, such as through initiatives for lead-free homes, also exist. It is, of course, easier to control risks that are never introduced into the housing sphere. Therefore, living in new housing stands to benefit occupants. However, the most vulnerable groups are often the least likely to benefit from such advantages.

ENERGY INSECURITY AND INTERSECTIONAL INEQUALITIES

Research has demonstrated that socioeconomic status and race are predictors of neighborhood, place, and presence of other hardships that can lead to or exacerbate energy insecurity. For example, residents in low-income and minority neighborhoods tend to experience issues such as increased exposure to environmental hazards, a lack of investment in housing maintenance, and poorer quality housing, all of which contribute to energy insecurity. Moreover, poverty and material hardship are complex issues in and of themselves, whereby the inability to meet basic needs extends far beyond any one category. In this section, we explore the overlapping issues that intersect with energy insecurity.

Socioeconomic Status, Race, and Place

The coalescence of socioeconomic status, race and neighborhood factors can lead to or exacerbate energy insecurity and present other hardships as well. For example, racial residential segregation, a proxy for concentrated neighborhood disadvantage, is a demonstrated predictor of energy insecurity (103). Black and Latino/a-headed households are more likely to live in an energy-insecure household because of their home's lack of energy efficiency (103). For example, NYCHA housing, predominantly inhabited by minorities, is facing a backlash over its dilapidation and lack of maintenance, which has resulted in widespread power outages, lack of heating, and the presence of mold and lead problems (79). Of these issues, NYCHA has been criticized severely for the persistent lack of available heat in its properties due to faulty boilers (104). In the winter of 2017/2018, ~80% of NYCHA residents faced a heat outage, which lasted 48 hours on average (105). Some advocates state that the difference in regulations for NYCHA housing compared to private housing is unjust and disproportionately disadvantages low-income communities of color (79, 106).

Low-income and minority neighborhoods collectively bear the brunt of more environmental hazards in and outside of their individual households (50, 107). For example, the siting of highly-polluting sources such as bus depots, landfills, highways, and plants or factories tend to be located in low-income communities. Low-income homes are also more likely to have maintenance defects, rodents, mold, and other poor housing conditions (66). Households in low-income and minority neighborhoods are also more likely to be overcrowded; this is especially true for immigrant populations in New York City and other urban areas. Overcrowded homes are associated with psychosocial stress, disease outbreaks, and higher asthma rates; they are also a predictor of the existence of other physical and social housing-related hardships that contribute to the burden of disease (93, 98, 108).

Furthermore, institutional and systemic racism and place-related social factors are drivers of higher rates of energy insecurity for minority populations. Ethnic minorities, immigrants, and indigenous groups are some examples of people who experience housing discrimination (57), a barrier to accessing more energy-efficient homes. Gentrification in many urban areas in the U.S is another social process that perpetuates

racial and ethnic disparities in energy insecurity prevalence. Gentrifying or newer residents are less likely to experience energy insecurity or have an energy inefficient home compared to longer-term residents who live in older households in the area (97). Long-term residents of Washington Heights in New York City, for example, are Dominican immigrants and African Americans, and they suffer far more energy insecurity than new neighborhood residents (64).

Neighborhoods and Spatial Inequality

Energy insecurity, as we have noted, is highly correlated with spatial inequality, where residents of different neighborhoods are more or less likely to experience energy insecurity due to their neighborhood's economic, environmental, and social makeup. The mean annual energy use intensity (EUI), which is a proxy for energy insecurity by way of high energy use from low housing efficiency, is much higher in urban areas that have lower socioeconomic status, less education, and more racial minority dwellers (65, 103). In cities that are more racially segregated, neighborhoods with low-income and minority populations are more likely to suffer from difficulties in affording or accessing energy (65, 109). As the gentrification of urban areas continues, racial residential segregation increases such that lower socioeconomic status populations are forced to live in areas that have substandard conditions both in housing quality and neighborhood characteristics.

Low-income and racial-minority neighborhoods in urban areas often suffer from the highest amount of environmental hazard exposure through air and noise pollution and substandard sanitation (110). This increased prevalence of environmental hazards can contribute to the health impacts of existing energy insecurities. For example, housing with poor ventilation in an area with high levels of air pollution can aggravate a child's asthma. There are well-established, clear disparities in neighborhood rates of asthma due to both indoor and outdoor environmental hazards (50), and there is an association between neighborhoods with energy insecurity and asthma prevalence (22). There is also spatial inequality and disparity in the prevalence of psychosocial stress. Low-income and minority neighborhoods suffer from higher rates of stress, which can compound the negative health effects that result from their already-increased exposure to environmental hazards (e.g., air pollution) (111). For example, family stress combined with exposure to neighborhood violence has been found to increase the incidence of traffic pollution-induced asthma in children, due to the strain on psychosocial pathways (112). The spatial disparities in energy insecurity and health also exist between urban and rural areas, where some low-income rural communities do not have access to natural gas or even electricity services, whereas lack of access to electricity services is rare in urban communities (113).

Bundled Hardships: Energy and Other Insecurities

As demonstrated by this robust review, energy insecurity is a complex problem, and it does not occur in a vacuum. The hardship of energy insecurity intersects with other hardships,

such that each compounds the severity of the others and contributes to detrimental health consequences. Competing needs and hardships, such as food insecurity, water insecurity, and housing insecurity, result in tradeoffs where basic needs are prioritized and sometimes foregone (9, 114, 115). The stress from having to make trade-offs between basic needs for food, water, housing, and energy profoundly affects adult and child mental health (116, 117), which can exacerbate many kinds of physical health and social issues.

With food insecurity, the "heat or eat" dilemma occurs when households must decide whether to expend resources on proper nutrition or adequate energy services because they cannot access or afford both (28, 30, 118, 119). Often, this dilemma leads to undernutrition, especially during the winter and summer months when there are higher energy use needs when it has been found that low-income adults and children have decreased caloric intake compared to lower-energy use months in the spring or fall (28, 118). Other health impacts from food insecurity include acute hospital visits, poor diabetes control, developmental delays, fatigue, and behavioral issues in children (54, 120, 121). In response to high energy bills, people also opt out of medical and dental care, which can lead to worse health outcomes in the future (119).

Water insecurity is another co-occurring hardship. Water and electricity tend to be dependent on one another. On a large scale, hydroelectric dams need water and electricity to function, power plants need cooling water when there are high temperatures, and nuclear plants use large volumes of water (122–124). It is not only water that is needed for energy, but the other way around as well. At the community and household level, access to hot water can be encumbered by energy insecurity (30, 41). When concerned about the cost of energy, some residents may cut back on hot water use (30). Furthermore, water pipes can freeze if there is a fuel shortage or shut-off in time of freezing outdoor temperatures (31). Without water, people's ability to access energy reduces.

Lastly, housing insecurity is a frequently cited competing hardship to energy insecurity (22). The dimensions of housing insecurity include frequent moves, lack of housing options, homelessness, high housing costs, overcrowding, and unstable neighborhoods (125–127). Households that do not have enough money to afford high-quality housing also suffer from an inability to pay high utility bills, which can result in household debt owed to utility companies. Low-income families juggling financial hardships often prioritize other financial obligations such as paying for rent or groceries, seemingly more immediate needs, over paying off debt; this behavior can leave families in prolonged debt cycles (128). Debt owed to utility companies often prevents low-income households from moving because utility debts are not transferable (9), forcing residents to continue living in poor-quality housing. A home cannot be rented without a utility account in the renter's name, which is not possible if they have arrears at another address (9). Frequent moving is also a common form of housing insecurity. Low-income families are five times more likely than higher-income families to experience eviction, resulting in a move (50, 129). Evictions generally occur when rent prices increase beyond what a family is capable of affording. Utility shut-offs play an important role in housing insecurity,

as they are often the precursors to eviction. In both instances, households may encounter the double burden of housing and energy insecurity (23). As gentrification spreads across US cities, urban housing affordability is unachievable for most low-income families, forcing evictions, moves, overcrowding, and an increase in homelessness, and while newer buildings often enjoy energy-efficiency upgrades, older homes and buildings, which are often less efficient and more expensive to operate from an energy cost perspective, do not receive such upgrades (64, 130). In short, energy cost burdens can increase housing affordability strains whereas lower energy bills can protect against high housing costs and promote residential stability.

ENERGY INSECURITY, HEALTH, AND COPING

Health issues are linked to energy insecurity. In particular, such direct health outcomes are often a result of indoor temperature extremes and inadequate energy access. Thermal stress occurs when residents are unable to heat or cool their homes properly, frequently due to unaffordable utility bills or an inability to access adequate services. As a result of inadequate home energy, residents resort to coping strategies, which, with chronic use, can be taxing and overburden resilience reserves.

Improvising and Coping Without Energy

Residents implement coping strategies to manage and respond to unmet energy needs; we consider this to be the behavioral dimension of energy insecurity. Despite the ingenuity and agency many people demonstrate in the face of suboptimal energy circumstances, these coping strategies have negative health implications. One such coping strategy is the use of emergency energy technology (i.e., generators), which is generally reserved for disasters but is often employed by energy-insecure households. Generator use is strongly associated with carbon monoxide (CO) fatalities, especially when the generator is placed incorrectly in the household (e.g., in the garage or outside of a bedroom window) (35, 37, 131). Even when placed correctly, generators constantly release CO, which in small, consistent doses can lead to cognitive decline, headaches, nausea, and dizziness. Maintenance issues can aggravate the health impacts of some coping methods, such as poorly maintained households exposing people to higher levels of toxins (50). For instance, some residents living in low-quality housing use unvented gas heaters as their primary heat source and/or hot air units that do not have ducts because they are unable to afford or access improvements. Both practices are associated with increased levels of nitrogen dioxide (NO₂) and volatile organic compounds (VOCs), which exacerbate allergies and respiratory illness symptoms, create ear, nose, and throat irritation, and contribute to cognitive delays (51, 132). People also resort to avoiding energy sources in their homes or use extreme conservation strategies to reduce energy expenditure. For example, some avoid using a refrigerator, which is associated with undernutrition due to a lack of fresh food in the diet, and/or avoiding hot water use, which can lead to infections and hygiene-related illnesses. Other survival strategies include

practices such as only heating one room of the house, going to bed early, and using low lighting (114).

Cold Stress and Coping

In the winter, cold homes due to a lack of proper heating lead to excess deaths and a number of health problems (13, 47, 69, 99, 100, 133, 134). Cardiovascular symptoms as a result of inadequately heated homes are a prevalent cause of medical issues (69, 135), and rates of hypertension increase in cold temperatures, which can lead to strokes and heart attacks (69, 74, 101, 135). The elderly and people that are already diagnosed with CVD are more at risk of heart attack and stroke due to cold stress (13, 47). Furthermore, research has found that arthritis symptoms worsen in cold homes (12). The rate of pneumonia and other infections, mostly among children, increases due to suppressed immune function from the cold (70), and upper and lower respiratory symptoms, such as coughing and wheezing, are worsened by the cold as well (69, 99, 100). Asthmatic residents and caretakers of asthmatic children living in inadequately heated homes report higher rates of poor well-being and more frequent hospital visits (27, 136). Alzheimer's patients have a higher rate of mortality from a combination of physiological and behavioral factors as a result of the cold (137). Poorer well-being and financial strain from an increased number of medical visits can exacerbate mental health issues, such as depression and anxiety, that may already be heightened due to the stress of energy insecurity (114).

In response to a cold home, many households cope by using alternative heating methods that have a direct impact on health (23). For example, using generators and stoves to provide heat also results in the release of toxic gasses such as NO₂ and CO that can impair cognitive function, exacerbate respiratory illnesses, and cause mortality (35, 49, 51, 138–140). The use of space heaters or ovens as alternative heat sources can also increase the risk of fire and injury, which could potentially lead to displacement or death (23, 104).

Heat Stress and Forbearance

Heat stress occurs when households are unable to afford or access energy to cool their homes. The health effects from this type of energy insecurity, such as increased morbidity and mortality rates, are most often seen during heatwaves when excess heat from outside conditions creates heat stress (135, 141, 142). Cardiovascular issues such as heat strokes, hypertension, and heart attack, dehydration, hyperthermia, and nervous system morbidities are examples of health impacts that occur under heat stress (69, 135, 143). Other health effects include a higher likelihood of acute renal failure (42) and increased sleep disturbances as a result of the extreme heat in inadequately cooled homes, which can exacerbate mental health conditions triggered by the stress of energy insecurity (53, 57). This increase in morbidity and mortality is motivated by other social determinants of health that predict energy insecurity (142).

Coping mechanisms for dealing with heat stress have their own related stressors and issues. For example, opening windows for ventilation and relief from heat may seem like an easy, free solution to cool down warm homes; however, in neighborhoods

that are perceived to be unsafe, many people cannot or do not travel to cooler locations nor do they leave windows open due to fear of crime and violence (141, 144). Furthermore, open windows expose households to noise pollution, particularly in urban areas where there is high traffic flow, which causes sleep disturbances and obstructed concentration on tasks (57). Open windows also increase the infiltration of outdoor air pollution, such as from motor vehicle exhaust, that is associated with respiratory and cardiovascular health risks (57).

High-Effort Coping and Resilience Reserves

Energy insecurity plays a role in depleting a person's resilience reserve (24). The *resilience reserve* framework offers a different lens than does past resilience research, which found that marginalized groups were less resilient because they had less social and material support and more life stressors (145). The resilience reserve framework argues instead that marginalized groups that contend with social, economic, medical, physical, and geographic vulnerabilities expend resilience resources to manage everyday hardships, leaving less opportunity to accumulate the psychological and material means with which to respond to and recover from large shocks such as extreme climate events (24). Therefore, after a disaster, marginalized groups have greater difficulties coping and rebounding, because they have already depleted their reserves. For example, years after Hurricane Sandy, which occurred in 2012, low-income NYCHA residents reported longstanding physical and psychosocial difficulties, citing the Hurricane's exacerbation of existing hardships and emotional trauma (24). Specifically, NYCHA residents cited the lack of electricity, heat, and functional elevators as a source of struggle, not just after the Hurricane, but before it as well. Housing, economic, and energy-related hardships had long been a source of chronic stress, constantly gnawing at their resilience reserve before the hurricane hit (24). One risk of an increased frequency of extreme weather events is the potential to exacerbate existing hardships and deeply impact the resilience capacity of vulnerable populations as they confront a growing number of social, economic, health, and energy challenges on a normal basis.

DISCUSSION

Energy insecurity is a multifaceted phenomenon with short- and long-term iterations influenced by social determinants and a changing climate, ultimately impacting health. This paper reviews existing literature in order to trace the pathways by which chronic and acute energy insecurity directly and indirectly result in various adverse health conditions. Our heuristic model is a unique contribution to the literature that intends to depict seemingly far-flung factors associated with energy, poverty, health, and climate change. We demonstrate the disproportionate effects on vulnerable populations and the mechanisms of household energy that lead to poor health and excess death. Contributors to acute energy insecurity include power outages, fuel shortages, supply issues, and shut-offs stemming from affordability challenges. For the most part,

these acute issues are short-lived, though their impact can still be significant for short- and long-term health, well-being, and survival. Meanwhile, the fundamental causes of chronic energy insecurity are rooted in socioeconomic disadvantage as determined by race, income, educational level, position within the life course, and medical conditions that affect energy needs and dependency. It is also deeply affected by housing quality and the concentration of inefficient housing at the neighborhood level that is unfortunately closely patterned along the axes of social inequality and racial residential segregation. The literature suggests that the social determinants of health, housing characteristics, and neighborhood quality seem to predict and/or exacerbate household energy insecurity. As a result, residents turn to coping methods that can have a number of negative health consequences, such as toxic exposure from generators, fires from space heaters, noise pollution and crime from open windows, and many more. Energy production and infrastructure, both globally and locally, contribute to energy insecurity in terms of access and environmental degradation. High energy demand can strain systems, weather events can create power outages, and affordability issues can lead to shut-offs and arrearages. The result of such energy insecurity contributes to outcomes such as psychosocial stress and mental health issues, poor sleep, cardiovascular and respiratory issues, and heat stress, among others. These energy-related difficulties can also deplete people's resilience reserves, such that affected populations are less able to bounce back from acute and chronic hardships. In the context of climate change, more wear-and-tear on the energy systems, housing infrastructure, and population health seems inevitable.

The following discussion offers a critical analysis of the vast but disjointed literature on energy insecurity. One critique of the present literature is that much of it lacks an environmental justice framework, which should be integral to energy insecurity research, and we exemplify this issue by discussing the lack of intersectional consideration of the rising wealth gap, coupled with increasing urbanization, and energy transitions. Second, we explore connections to energy-related issues in the Global South. Although the Global South was not the focus of this review, energy-related issues are prevalent across countries in Africa, Asia, and Latin America and must be taken into consideration when designing interventions, because energy reform anywhere has global implications. Lastly, we discuss the current and future impact of climate change on energy insecurity and the need for greater consideration of climate change when conducting research on energy insecurity. We contend that the use of acute and chronic energy insecurity terminology can be helpful to researchers using a climate change framework because it separates the direct energy-related effects of climate events (acute) from more long-term effects (chronic).

Wealth Inequality, Urbanization. Energy Transitions, and Environmental Justice

As energy becomes more expensive and the wealth gap increases in the U.S., poorer households may have greater difficulty affording adequate household energy. The difference in the

proportion of income allocated to paying for energy bills could grow wider between the rich and the poor; low-income households may increasingly spend a higher proportion of their income on energy bills, because energy bills may increase at a rate faster than does their income (22). In contrast, wealthier households may experience an increase in their income at a rate that can sustain the increased price of energy. Take, for example, the yellow vest protests in France, which were incited by increased fuel costs. Wealth inequality should be addressed in energy insecurity literature, not only to ensure that lower-income households can afford and access energy through evidence-based policy but because socioeconomic status plays a direct role in determining a persons' health environment beyond energy needs.

The growing wealth gap is influenced by the exponential influx of people to urban areas, which do not have adequate infrastructure to provide for the growing population. As urbanization increases, more people are expected to benefit from urban advantage—the idea that there are health benefits to living in urban vs. rural areas (146). However, higher-income urban residents tend to benefit more from the urban advantage, and more often, low-income residents are left in unhealthy, poorly maintained neighborhood and residential environments (146). Thus, poorer residents are left without support and endure intergenerational socioeconomic hardships that prevent families from accumulating wealth. Constantly coping with hardships is financially costly, and high energy bills can be an obstacle to saving money among low-income households (9). Higher-income residents, on the other hand, pay less of their household income toward energy bills and benefit from more efficient and comfortable living environments.

The growing wealth gap between black and white families could also worsen disparate racial impacts as it relates to the intersection of energy, health, and poverty (147, 148). Energy transitions from fossil fuels to renewables such as wind and solar may also contribute to a growing gap because white-collar businesses and wealthier households are able to control and obtain financing for renewable energy, whereas poorer, minority populations are unable to grow their use of renewable energy technology because the cost is prohibitive and access is difficult given the cost, lack of social capital, and lack of education around renewables (130). African Americans have been historically excluded from opportunities for social and economic mobility, and, in the energy sphere, they are also unduly burdened. The literature has failed to explicitly acknowledge the racial divides in energy-related hardship related to cost, comfort, and efficiency and the protracted uptake of the cleanest energy technologies among minoritized groups. It is important to recognize how an increasing wealth gap will perpetuate energy insecurity, further impacting the ability of low-income and minority families to afford adequate energy. Identifying racially based injustices has been critical to advances in environmental justice, and here too, we see a potential for greater analysis of the racial disparities in energy insecurity and related health and social outcomes.

Energy Insecurity and the Global South

While this review has focused on energy implications in the U.S. and the Global North, many of the same issues are relevant to the Global South. Few articles discussed in this review use a framework of intersectionality to discuss the burden that inordinately affects marginalized populations around the world. Research on global household energy insecurity that uses environmental justice and intersectional frameworks could more adequately analyze this topic. In the Global South, millions of households lack adequate energy sources (149). It is vital that we find methods to expand modern energy services to reach more of the population (150). However, more systematically speaking, energy is dispersed unjustly and inequitably around the world (151, 152). Some populations have greater energy access than they need, while others do not have enough (8). We know that reducing carbon emissions worldwide is vital for addressing climate change, but it is also important to address the unequal distribution of energy sources. Health impacts from energy poverty in the Global South exist partially due to limited access to modern energy technologies. One example is the increased risk of COPD and heart disease from air pollutants that stem from cooking with biomass fuels rather than using electric or gas stoves (7, 19, 153, 154). Households using biomass cookstoves, for instance, face the dilemma of inhaling toxic pollutants from cooking or not eating—both of which have significant health implications. About one-third of the world, almost entirely in the Global South, relies on solid fuel sources such as wood and crop waste for cooking fuel (5, 7). Burning solid fuels for cooking creates indoor air pollution, which is significantly associated with stroke, ischemic heart disease, COPD, lung cancer, and pneumonia. The health impacts of solid-fuel cooking disproportionately impact women and children, who are exposed to higher pollution due to spending a larger amount of their time cooking than do men. Of the 1.3 million COPD deaths among women, about 511,000 are attributable to indoor cooking pollution. In contrast, of the 1.4 million COPD deaths among men, a much smaller proportion—173,000 cases—are attributable to indoor cooking pollution (7). Increasing the prevalence of and access to cleaner fuels for stoves around the world could significantly reduce these negative health outcomes.

In the same way that people of color in the U.S. disproportionately experience energy insecurity, people of color and those living in lower-middle-income countries (LMICs) around the world disproportionately bear the burden of an inequitable global energy system. Globally, people of color bear the burden of household energy insecurity. To this day, 1.3 billion people, most of whom live in Asia, Latin America, and Africa, lack access to modern energy services (155). Of the total number of people lacking electricity access worldwide, 41.3% of the people live in African countries, 28.5% live in India, 27.3% live in other Asian countries, and 2.2% live in Latin American countries (155). Countries of color are also more likely to shoulder the impacts of climate change, though they are less responsible for carbon emissions and environmental degradation, and their ability to withstand and rebuild from weather events is lower than higher-income countries (156).

Climate Change and Energy Insecurity

The literature reviewed here does not adequately demonstrate a thoughtful link to climate change that goes beyond the concepts of adaptation and mitigation. Future research should examine the impact that climate change will have on energy insecurity. We propose that the concepts of acute and chronic energy insecurity may allow future researchers to expand upon and better evaluate the effects of climate change on household energy. Climate change worsens the direct and indirect health outcomes of energy insecurity and exacerbates cumulative risk, such that those already experiencing energy insecurity are most affected by climate events because they are less able to prepare for, respond to, and recover from disaster events (157). Communities that are most vulnerable to daily hardships are also most vulnerable to the impact of weather events, and the disparity worsens with repeated shocks from climate change (156). For instance, mortality from heatwaves disproportionately affects older, minority, and low-income residents who are less equipped socially, economically, and physiologically to withstand high temperatures. After the 1995 Chicago heatwave, there was clear demographic disparity in mortality rates—lower-income and older people died at much higher rates than the rest of the population (48). These populations were much more vulnerable to heat stress due to living in decaying housing, lack of access to medical services, and social isolation (48). Without movement toward addressing the world's substandard housing, medical, and financial systems, natural disasters could continue to disenfranchise marginalized populations, intensifying and worsening existing stressors. Though some of the literature critically appraised in this review discusses weather events, the vast majority did not explicitly discuss climate change. Research should incorporate and explore the detrimental implications of climate change when evaluating energy insecurity in order to better prepare for future climate scenarios.

While vulnerable populations tend to be hit harder by climate change-related weather events all people are affected by climate change. Climate change-related energy insecurity issues, therefore, could impact anyone regardless of socioeconomic status (158). Severe weather events will lead to acute energy insecurity such as power outages that can affect anyone. More frequent heatwaves will significantly increase energy demand, the need for expanded energy systems, dependence on household air conditioning for entire populations (45, 93, 141, 142, 159). Power outages from heatwaves and storms can put anyone at risk of medical difficulties. Furthermore, storms are increasing in frequency and severity all over the world, putting people at risk of cut off energy access. And regardless of socioeconomic status, people resort to using emergency energy systems (e.g., generators) or non-energy methods during storms or disasters, which puts residents at risk of CO poisoning (160). It is difficult for residents with chronic illnesses to withstand acute energy insecurity from storm-related power outages (141, 161). As shown in these examples, energy insecurity, particularly acute energy insecurity, may become more prevalent for all people as climate change worsens. Notwithstanding the importance of the issue, a demonstrable gap in the literature exists, given that only one-third of the sources

included in this review discuss climate change in relation to energy insecurity.

STRENGTHS AND LIMITATIONS

This review paper was inspired by a desire to comprehensively understand the predictors and outcomes of energy insecurity. The household energy literature spans many disciplines and research methods. As a result, we drew from a large interdisciplinary pool of research in order to capture enough relevant sources on this topic. The broad inclusion criteria allowed us to find articles that spanned many disciplines and methods to give us a realistic look at the full range of the household energy insecurity literature. Though the breadth of information about household energy is a strength, it was also challenging in that it demonstrated a clear lack of cohesion and systematic guidelines around research on household energy. Therefore, making connections and critiques across these fields of research and sources presented a formidable challenge, though we have done our best to synthesize the literature and draw conclusions from it. The papers vary significantly not only in focus but in scientific quality and rigor—some are more descriptive in nature, while others are more empirical. Many of the studies were not rigorously designed, and for the most part, the literature proved to be quite underdeveloped overall. This review did not assess for quality or eliminate studies on the basis of potential bias. The challenge of a highly dispersed evidence base led us to develop our heuristic model, which attempts to conceptually unify the literature on household energy and health.

CONCLUSION

When considering the substantial impact that inadequate household energy can have on population health, we recognize the need to adopt policies and practices that protect people from energy insecurity. This review sought to highlight how energy needs are important for all aspects of daily living and for protection against the effects of acute insecurities in the context of climate change. Climate change threatens life on earth as we know it, and our collective vulnerabilities to energy hardship need to be addressed with extreme urgency (162). By using energy insecurity as a framework for understanding the nexus of effects of unmet household energy needs, we can draw connections between the direct effects of inadequate household energy, such as hypertension from a cold home, and how social vulnerabilities and co-occurring hardships contribute to the problem. With this broader framework, we can begin to understand how policies that address food insecurity, housing insecurity, structural and institutional racism, neighborhood segregation, education inequality, income inequality, and so many other social issues, will also affect energy insecurity and together impact population health. Studying the energy–health–justice nexus through the lens of acute and chronic energy insecurity presents a novel and innovative direction for public health research, advocacy, and policy that can be used to improve the health of people in the U.S. and around the world.

AUTHOR CONTRIBUTIONS

SJ, SS, and DH contributed to the conception and design of the review, performed the analysis, contributed to manuscript revision, response to comments from reviewers, read and approved the submitted version of the review, and all accountable of all aspects of the review, including its accuracy and integrity. SJ organized the database and wrote the first draft of the manuscript. SS and DH wrote sections of the manuscript.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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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

PROOF OF SERVICE

I, Mark N. Templeton, certify that an electronic copy of the Accompanying Exhibits DAO-108 to DAO-117 (Part 2 of 5) for the Direct Testimony of Justin Schott on Behalf of Soulardarity and We Want Green, Too was served on the following on July 26, 2024.

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