Quadracci Sustainable Engineering Laboratory (QSEL)

Report Posted April 28, 2020

How do we heat our homes in the US?

And what does it mean for greenhouse gas emissions?

Michael Waite[1], Associate Research Scientist
Vijay Modi[1,2], Professor and Director QSEL

[1]Department of Mechanical Engineering, SEAS and [2]Faculty Earth Institute
Columbia University

In this report, we look at the residential space heating landscape in the U.S. and provide quantitative estimates of the fuel used and associated greenhouse gas (GHG) emissions. When it comes to reducing greenhouse gas emissions, the focus tends to be on integrating more renewables into the electricity grid: Wind and solar farms, battery storage, smart grid and new utility structures. Turning to an individual home, actions like installing rooftop solar panels and how to implement efficiency and conservation come to mind. However, an individual home whether a standalone house, one of a few units in a row house, or an apartment in a large multifamily building and its heating system hardware are inextricably linked to larger energy infrastructure and delivery systems.

Hence emissions from buildings and actions needed to achieve deep emission reductions from them require an understanding of where we are today across the country (continental U.S. for now) in order to chart our path forward. It took us tens of decades to get to where we are. We still use buildings a century old even as we changed fuels and clamped on newer heating systems to old. This is why space heating is particularly challenging and the snapshot today reflects the diversity of fuels and housing stock, how we use them within our homes and how those fuels get delivered to us and the diverse climate across the U.S. In this report, we illustrate the current status of space heating for residential building sector so that measures to reduce emissions can be understood as part of the broader energy decarbonization efforts. In a following report, we will look at specific pathways to deeper emission reductions in this sector.

Introduction

To keep our homes warm, we primarily burn a fossil fuel (natural gas, heating oil, propane) or use electricity (which is generated from some combination of fossil fuel and low-carbon resources). In 2018, residential buildings contributed 20% of all U.S. energy-related GHG emissions, including both on-site combustion of fossil fuels and emissions from electricity supply [1]. We estimate that nearly half (47%) of these emissions are due to space heating. The emissions are caused by a combination of weather, heating fuel and the prevailing heating systems. Hence the overall 47% figure does not capture how significantly the contribution of space heating varies across the U.S. Figure 1 shows the fraction of residential emissions from space heating as computed for each census tract (Figure 1(a)) and as aggregated at the state level (Figure 1(b)).

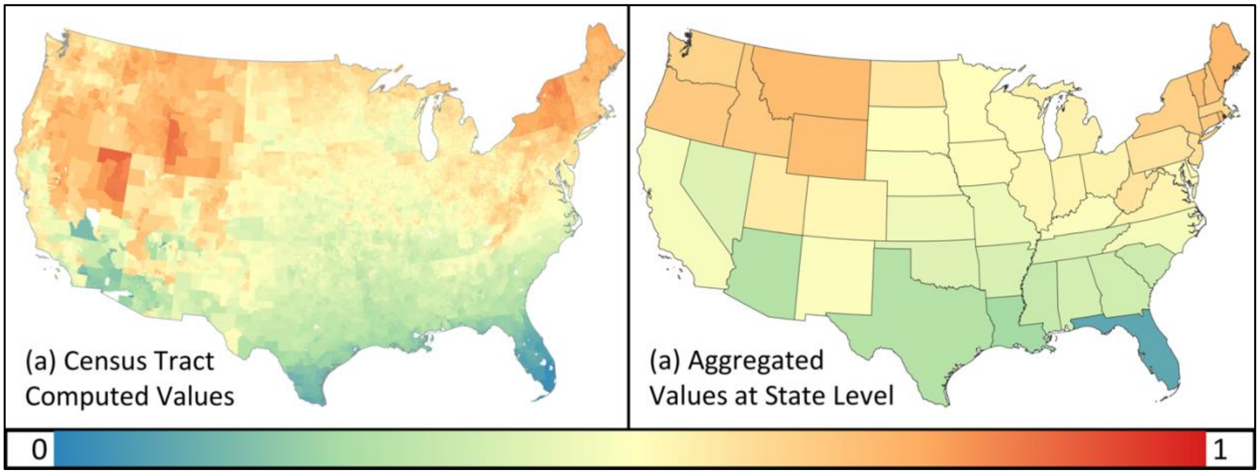


Figure 1 | Fraction of census tract residential greenhouse gas emissions from space heating (a) computed for each census tract and (b) aggregated at the state level. Note that color bar scale shown here and in the rest of the report is such that the values change linearly between the minimum value at the left and the maximum value at the right.

Aggregated across the U.S., and using data from years 2014-2018, we compute that annually nearly a billion tons of carbon dioxide equivalent (CO_2e) emissions were from residential energy usage (all usage, not just heating) in buildings. (CO_2 is the dominant greenhouse gas, so non-CO_2 GHG emissions are commonly converted using their global warming potential relative to that of CO_2 and added to the emissions of CO_2 to arrive at a single metric, CO_2e, where the “e” stands for “equivalent.”) Of these, nearly half (460 $MMtCO_2e$) are from space heating. Space heating emissions are either from on-site combustion of fossil fuels (about 60% or 286 $MMtCO_2e$) or from the electricity generated to supply buildings that use electric heating (remaining 40% or 174 $MMtCO_2e$). On-site combustion is through the use of boilers or furnaces that heat water or air which is then distributed within a building using pumps or fans to maintain warmth. (These values are computed using a model we described in [2] and do not include the emissions associated with electricity for pumps and fans.) It is important to recognize that while emissions from on-site combustion of one unit of a particular fuel are the same, those from electricity use change across the country and over time as the mix of generation sources used to produce that electricity changes. How exactly the electricity is used to heat the home matters enormously and the dominant current use is through the use of baseboard or resistive heating which is an inefficient means.

The numbers presented in the previous paragraph are large and, hence, difficult to visualize. Scaling down to 1000 square feet (sf) of residential space, the national average annual heating emissions would be 2.4 tCO_2e. Note that 1000 sf is not uncommon for an apartment unit; however, a single-family home in the U.S. is nearly 2500 sf on average and the emissions from heating such a home would be 6 tons of

CO_2e annually. But again, national averages alone hide the complexity of the space heating emissions, and we can better understand the current situation by investigating the underlying drivers of space heating emissions and how they vary across the U.S.

Space heating costs are a combination of upfront costs to purchase and install a system, the cost of maintaining those systems and the recurring cost of the fuel or electricity. In this report, we provide average values for the recurring cost components across the U.S. These costs are strongly dependent on the home's heating fuel and location, which shapes both the demand and the local cost of fuel and electricity. Even beyond these higher-level effects, every home is different in how it is built (e.g. thermal insulation levels), its heating system efficiency, and its occupants' use and comfort expectations. Readers should note that our estimates are a reflection of the current building stock and heating systems and are not an estimate of what's *possible* for a new, efficient home.

Let us look at a couple brief examples to illustrate how one could use the values presented in this report for average heating needs and fuel prices, depending on where you are in the U.S. We estimate the median U.S. home needs an average annual 35 MMBtu heat per 1000 sf; with efficiency losses, this would likely require in excess of 40 MMBtu natural gas (or 400 therms on a utility bill). At the average U.S. natural gas price of $10/MMBtu, heating this space would cost approximately $400 per year. Now, let us consider New York City, a place colder than the median U.S. and with higher fuel prices. Here, we estimate 50 MMBtu of heat is needed for 1000 sf. If we again consider natural gas heating with efficiency losses that necessitate 60 MMBtu of fuel, heating an average 1000 sf space would cost about $960 per year if the delivered natural gas price is the average $16/MMBtu for residences in New York State. Note that these prices themselves are location-specific and could change- as we see even during the writing of this in April 2020 with crude oil price collapse.

Drivers of Residential Space Heating Emissions

Space heating needs are highly temperature-dependent and the local climatology that drives temperatures also may affect whether how thermally efficient the local construction practices are. Further, the availability of heating fuels depends both on the supply chains within a region of the country and whether you are in an urban or rural setting. Homes themselves are also diverse in size, type of construction, effectiveness of insulation, air leakage, heating equipment, occupancy and how they are used. Rather than attempt to capture all of these effects – which is not possible given our limited knowledge of the full array of considerations – in this report, we investigate primary drivers of residential heating demands: (1) Climate, (2) heating fuel and (3) GHG emissions rate of electricity supply.

Climate

Cold winters are a primary driver of household heating needs and the resulting GHG emissions. A common measure used to capture local climate effects is "heating degree days," the number of degrees that a day's average temperature deviates below a reference temperature aggregated over one year or multiple years. We use a typical reference temperature of 65°F and show the annual heating degree days with 65°F basis (HDD65) across the U.S. in Figure 2 computed at the census tract level. Since weather changes year to year, the annual numbers shown here are obtained using average of a ten-year 2008-2017 temperature data set.

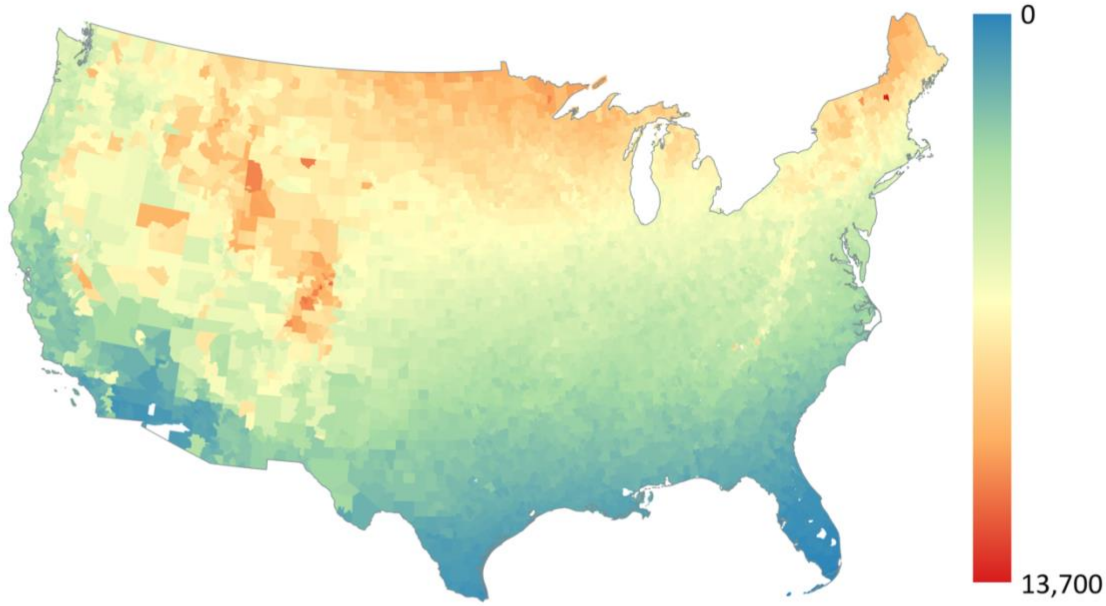
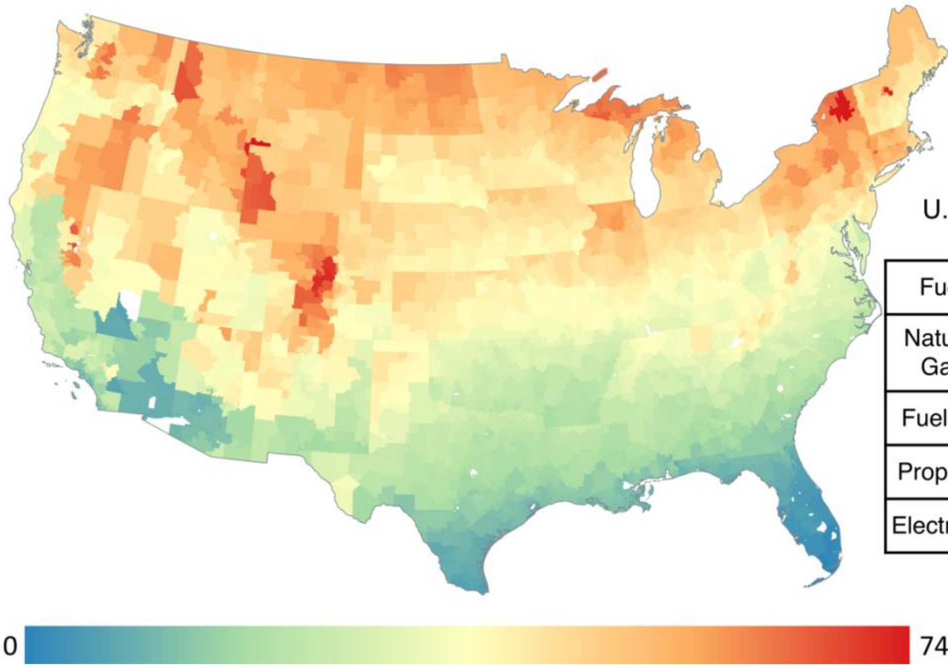


Figure 2 | Heating degree days with 65°F basis. Annual values computed using temperature data for 2008-2017 as described in [2]. The maximum computed census tract HDD65 is 13,710; 0.1% of census tracts have computed HDD65 greater than 10,000.

As noted above, how climate translates to actual space heating demand is dependent on many factors related to the efficiency and systems in buildings themselves. Based on a novel model developed for a recent publication [2], we computed the space heating energy required per 1000 sf at the census tract level, as shown in Figure 3. (We have included a map of the underlying model temperature-dependent heating demands, which were determined at the state level, as Appendix Figure A1.) Figure 3 also includes a table of the range of fuel costs across the U.S. (2018 values per the U.S. Energy Information Administration) to reference for computing average energy costs. Note that Figure 3 shows the amount of heat delivered to the space and does not include efficiency losses in heating equipment. It is not uncommon for boilers and furnaces to only deliver 85% to 90% of the heat possible from burning the fuel purchased even though newer technologies can push this figure to 95%. Based on U.S. average values, one can deduce that heating with fuel oil or propane in 2018 cost approximately 2-2.5 times as much as heating with natural gas; because electric resistance does not have the same efficiency losses as combustion fuels, its heating costs would be expected to be approximately 3 times those of natural gas heating.

(There are other electric heating technologies discussed later in this report.) Note that these energy costs vary considerable across the country and readers should refer to Appendix Tables A1 and A2 for location-specific values.



U.S. Residential Energy Prices ($/MMBtu)

Fuel	Min	Max	Avg
Natural Gas	6.86	20.60	10.14
Fuel Oil	17.85	29.42	23.56
Propane	14.54	52.31	26.47
Electricity	23.77	49.59	36.63

Figure 3 | Computed annual residential space heating energy per 1000 sf floor area at census tract level. As computed per [2]; see Appendix Figure A1 for underlying space heating energy temperature dependence. Inset table presents the range of 2018 state-level average fuel prices (natural gas [3], fuel oil and propane [4]), eGRID region electricity prices [5], and average U.S. prices for each fuel source for residential customers. Note: Heating energy values are for heating delivered to the space and do not account for the efficiency of heating equipment.

Heating Fuels

The ability of a homeowner – and certainly a renter – to choose what heating fuel to use can be limited. As seen in Figure 3, delivered prices of natural gas are generally lower than those of fuel oil and propane. But while fuel oil and propane can be stored in tanks on customer premises, natural gas distribution relies on pipeline infrastructure that does not extend everywhere. Figure 4 shows the distribution of household heating fuels across the contiguous U.S. at the census tract level. The lowest emission fossil fuel, natural gas (53 $kgCO_2e/MMBtu$), is typically limited to more densely populated areas where distribution infrastructure is feasible, the areas that “light up” in Figure 4. Still, it is the dominant heating fuel in the U.S.: We estimate natural gas to heat 49% of residential floor area, provide 53% of all residential space heating energy (due to its being more prevalent in colder climates), while contributing 45% of all space heating-related GHG emissions.

Fuel oil and Propane, predominantly used in more rural areas (and in legacy buildings in older cities) have higher GHG emissions rates and fuel costs that make them particular targets for emissions reductions. Fuel oil tends to be concentrated in colder areas, almost exclusively in the Northeast: 80% of all fuel oil heating is in the states from Pennsylvania and New Jersey north through New England. Because of this geographic concentration in cold climates, we estimate fuel oil to provide 9.3% of all U.S. residential space heating despite heating only 6.7% of residential floor area. Further, because fuel oil has the highest emissions rate among common heating fuels (75 kgCO_2e/MMBtu), it contributes 11% of all space heating-related emissions. Propane (62 kgCO_2e/MMBtu) is a lesser contributor to overall space heating (6.6%) and GHG emissions (6.4%), but can be found in rural areas throughout much of the U.S.

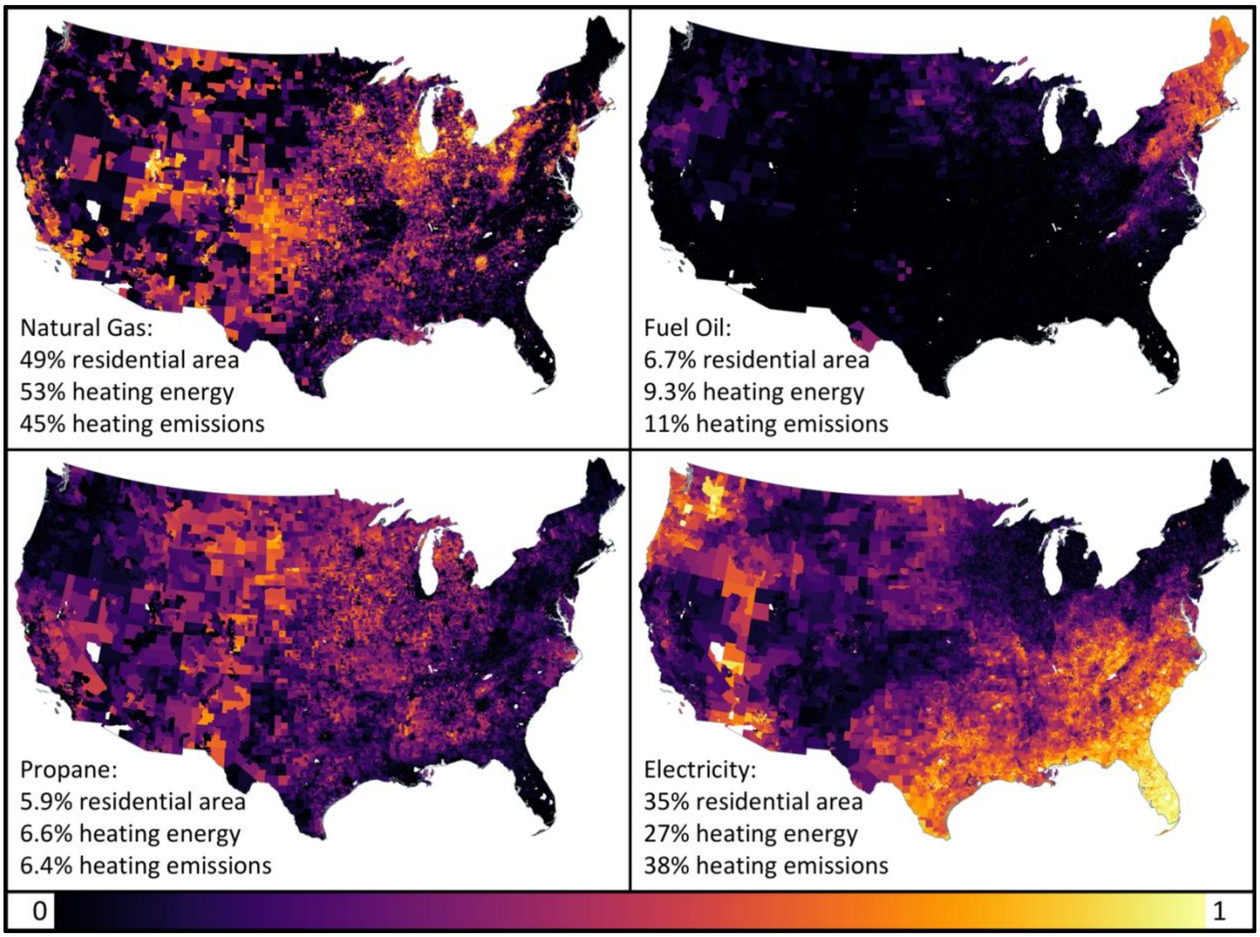


Figure 4 | Fraction of household heating provided by each fuel at census tract level [2]

Because natural gas is more prevalent in denser areas, and fuel oil and propane are more common in rural areas, the computations shown at the census tract level (Figure 4) can mask the very significant reliance on natural gas for heating. Figure 5 makes it easier to visualize the fraction of heating in each state provided by each of the same fuels. Natural gas provides more than 50% of space heating in 20 states and the District of Columbia; it is also the most common heating source in another 13 states.

Fuel oil is the dominant fuel in Connecticut, New Hampshire, Vermont and, especially, Maine. Beyond the mid-Atlantic and Northeast states, North Dakota is the only state with more than 5% of heating from fuel oil. Electricity is the dominant source of heating in 15 states, including all of the southeast plus Washington, Oregon and Arizona. In these 15 states, natural gas is also a significant source of heating (more than 25%) with the exception of Florida. Propane is more evenly distributed across the U.S., though it is much more common in colder rural states. (Note that these are general comments on the states' heating energy fuel composition; many factors, including socioeconomic ones, drive what fuel is used in particular buildings where multiple fuels are available.)

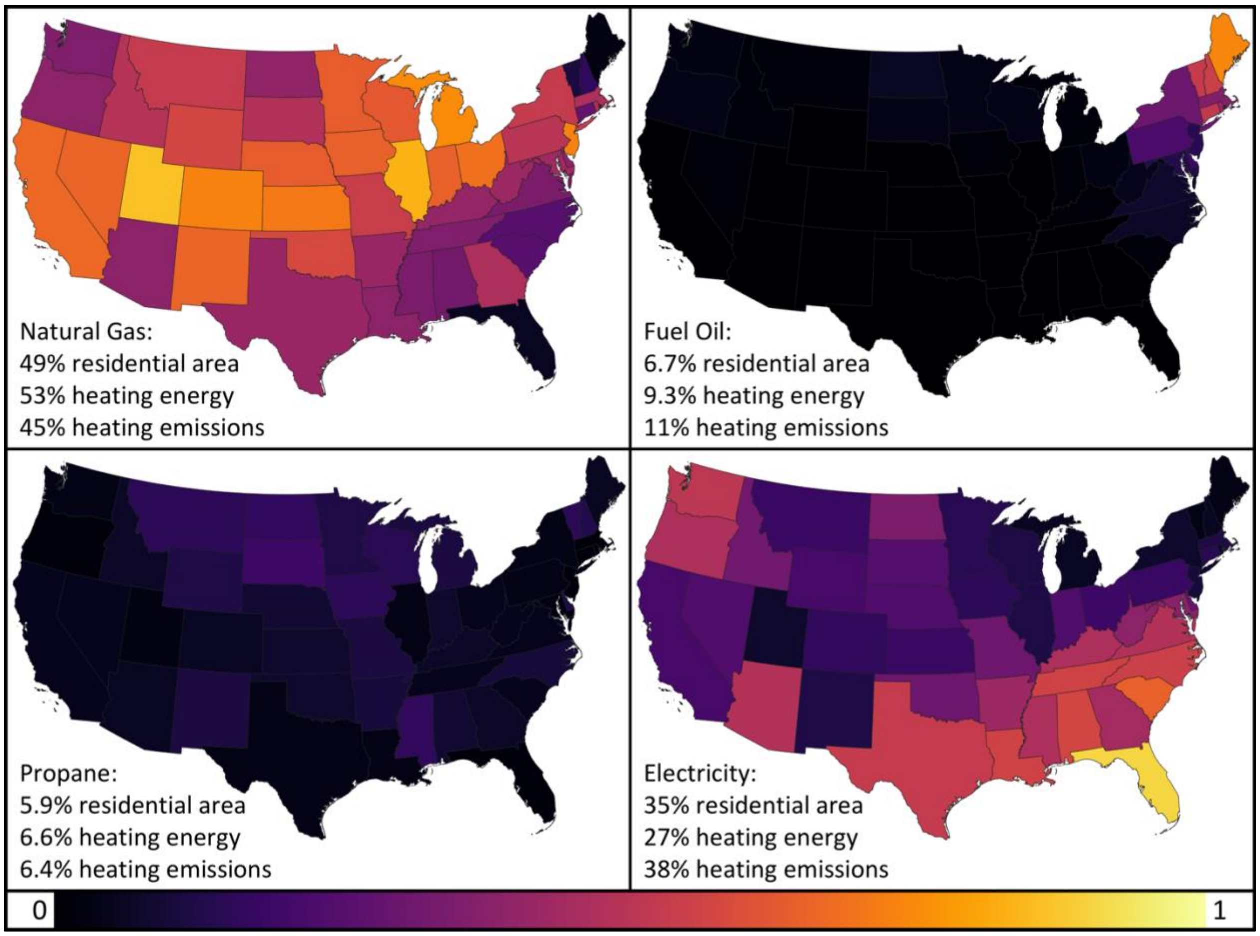


Figure 5 | Fraction of aggregate state space heating energy provided by each fuel

Electric heating is widespread in the U.S and heats 35% of residential floor area. Prevalence of electric heating has generally been associated with factors such as lower local electricity prices, shorter heating seasons and smaller heating loads, smaller living spaces, and whether a residence is owner-occupied or a rental unit. Since it tends to be used in areas with lower heating loads, it provides only 27% of heating energy. However, aside from the hydropower-rich Pacific Northwest, electric heating tends to be used in areas where it is largely generated by coal (and fossil fuels more broadly). We thus compute that electric heat contributes 38% of all residential heating emissions while providing only 27% of the heating energy.

Electric resistance heat (commonly baseboard electric systems, essentially a room-by-room installation of an electric heating element) is the least expensive system to install, but with the most expensive energy costs almost everywhere in the U.S. Electric resistance heat works on the same principle as the perhaps more familiar portable electric space heater. While electric resistance heating is technically nearly 100% efficient, such systems are costly to operate and produce high GHG emissions because of the energy sources used to produce that electricity (see below). An alternative that can significantly reduce energy demand and hence recurrent costs is an electric heat pump (EHP). An EHP, for the unfamiliar reader, is the same technology as in most air conditioning systems; a reversing valve allows such systems to provide warm air to a living space directly or through a central fan-duct system[1].

Some EHPs are capable of operating with an “efficiency” that exceeds 500%; this efficiency metric in technical jargon is called the “coefficient of performance” (COP) of the heat pump, the amount of heating delivered per unit electricity consumed. While such high performance is possible at more moderate outside temperatures, both COP and capacity degrade as temperatures drop, and electric resistance heating is eventually required. Given these temperature effects and higher upfront costs, EHPs were not widely used in much of the U.S., but they are becoming more common, now representing 27% of all electricity-based heating [6]. This is largely due to continuous improvement of EHP technology and the emergence of "cold climate heat pumps." For example, older EHP models may have operated as electric resistance below 32°F, but many modern EHPs can maintain a COP of 300% at that temperature, even exceeding 200% below 0°F. Still, the GHG emissions from EHP heating are highly dependent on outside air temperatures and the source of its electricity supply.

Electricity Emissions Rate

The resources used to generate electricity can vary considerably depending on where you are located in the U.S. The Environmental Protection Agency (EPA) eGRID subregions (see Appendix Figure A2 for subregion bounds and abbreviations) are useful for evaluating emissions from electricity in different parts of the U.S. Some areas of the U.S. are still highly reliant on coal (exceeding 70% in parts of the Midwest), whereas others have eliminated its use (New York State). Some areas have large amounts of renewable energy (58% in the hydropower-rich Northwest Power Pool and 25% non-hydro renewables in California), significant amounts of nuclear power result in large total amounts of low-carbon electricity in others (70% in upstate New York with both hydropower and nuclear power), while others remain nearly entirely dependent on

[1] Heat pumps that heat water are also available. These are currently more common in Europe. In this report, we focus on air-to-air or air-source heat pumps (ASHPs). Another alternative is a ground-source heat pump, which has improved performance at low temperatures, but with significantly higher cost, complexity and site-specific feasibility; a GSHP could certainly be the best choice for some homes.

fossil fuels (more than 90% in parts of the upper Midwest and 99% in Long Island, NY). As a result, electricity emissions rates can vary significantly across the U.S. (Figure 6).[2]

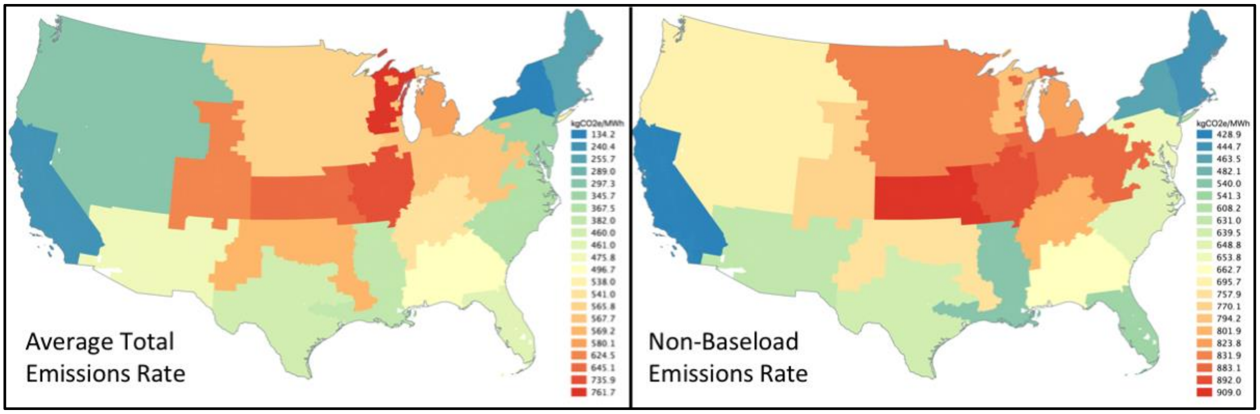


Figure 6 | Total and non-baseload grid subregion greenhouse gas emissions rates [7]**. Note that the values shown are in kgCO2/MWh and range from 134 to 762 in the left panel, whereas on the right panel they range from 429 to 909.**

The operation of individual generators and the resulting time-dependent grid emissions rates require complex models that are beyond the scope of the current report. However, it is useful to understand the difference between baseload emissions rates and non-baseload emissions rates, particularly in areas where there are significant contributions from nuclear power and hydropower (almost exclusively considered baseload generation) given the low-emissions of these technologies. In this report, we consider electricity for heating to be non-baseload. One further note: Not only is the current state of the grid highly regional, but so is the evolution of the grid and the incorporation of more low-carbon electricity – the vast majority of which is likely to be wind and solar power – to reduce GHG emissions and meet policy goals. We largely leave this rich topic for separate reports.

Greenhouse Gas Emissions from Home Heating Systems

Here we compile results from emissions computed for six different heating sources: Natural gas, fuel oil, propane, electric resistance and two EHP technologies. Heating efficiencies of 95% for natural gas and 85% for fuel oil are assumed based on the U.S. Environmental Protection Agency's EnergyStar ratings [8]; propane heating efficiency is assumed to be the same as natural gas. The two EHPs considered here are both ASHP and represent the median performance and 90th percentile performance ("state-of-the-art") "cold climate" EHPs in a regularly updated database [9]; Combining these

[2] The picture is actually more complex: on the one hand, loads closer to low-carbon resources could be thought of as having lower emissions rates than those farther away; however, large hydropower, nuclear plants and wind/solar facilities that reduce this local grid emissions rate might only make economic sense if there are (perhaps distant) dense loads to serve. On the other hand, the electricity system is a massive interconnected machine and the source of an individual electron cannot necessarily be tracked; however, we can also reasonably isolate electricity flowing to an outlet in Maine from a coal plant in Indiana. De Chalendar et al have quantified the differences between generation- and consumption-related emissions [11]. For straightforwardness and to make use of readily available data, we use eGRID values directly [7].

performance metrics of heating technologies and the heating demands computed earlier, we show in Figure 7 the residential space heating GHG emissions in tons of CO_2e per 1000 sf, computed at the census tract level for each of these heating sources.

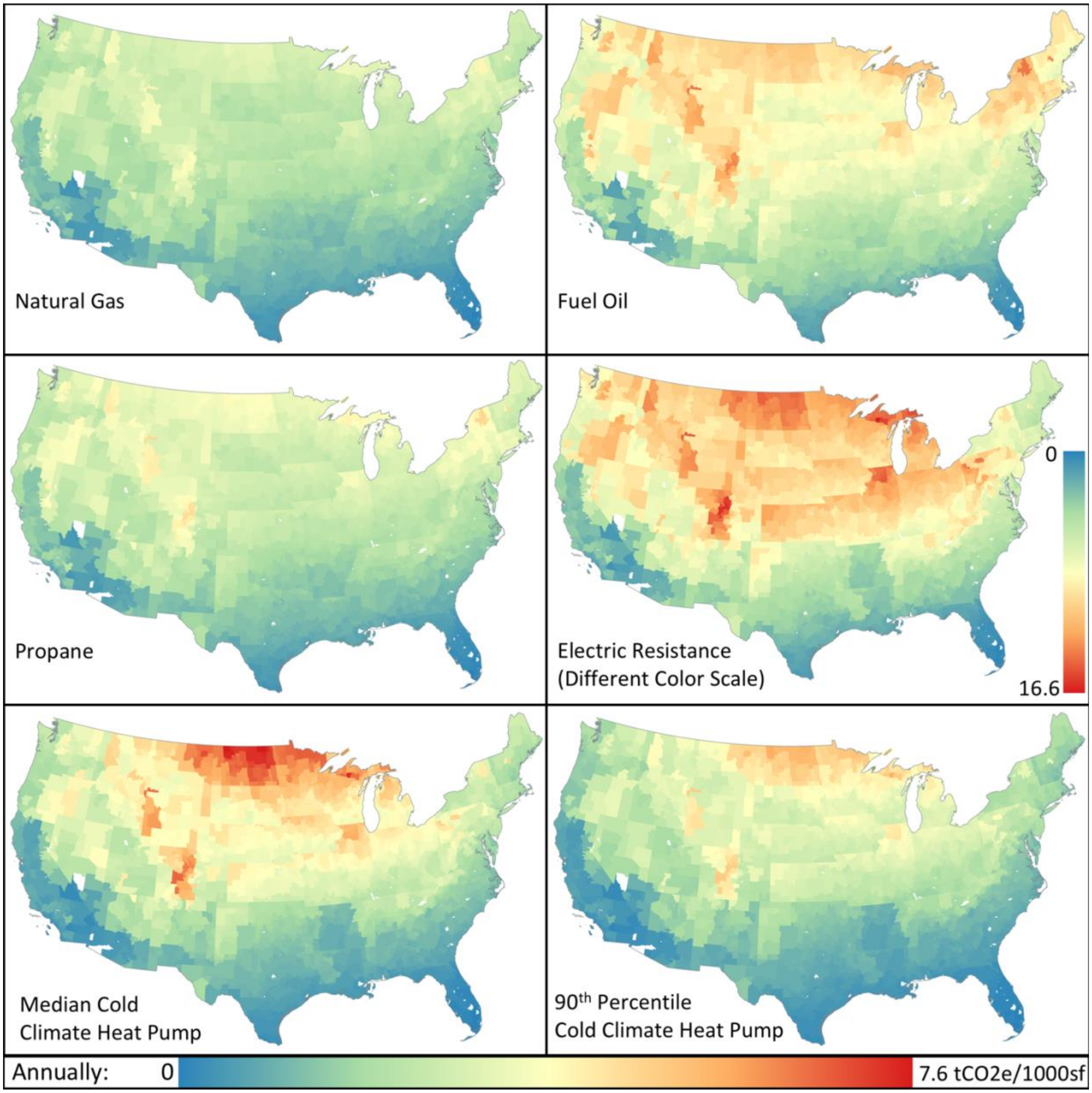


Figure 7 | Computed annual residential heating greenhouse gas emissions per 1000 sf for different fuels and electric heating equipment. Note: A different color scale is used for electric resistance and a separate inset color scale is shows that scale.

The most straightforward interpretation of the figures is that GHG emissions from using fuel oil for heating are higher compared to natural gas due to fuel oil's 41% higher emissions rate. A lesser effect is observable for propane, but propane's GHG emissions rate is only 16% higher than that of natural gas. A more complex situation is observed for electric resistance heating. Here we can see that the combination of cold climates (Figure 2) and high emissions rates (Figure 6) results in very high home heating emissions in much of the upper Midwest and Rocky Mountain areas. (Note that a separate inset color scale is used for electric resistance than all other options.)

While the location-specific electricity grid emissions rates complicate the landscape of electricity based space heating, there is one clear takeaway: Computed GHG emissions from electric resistance heating are higher than natural gas heating in all census tracts. This is largely because even where low-carbon resources are used for electricity generation, non-baseload electricity is largely dependent on fossil fuels throughout the U.S. Therefore, the *marginal* emissions rate associated with electric heating is almost always higher than the overall emissions rate.

The higher COPs of EHPs do lead to lower emissions when compared to electric resistance heating. We compare EHP emissions to those from natural gas heating: With current median cold climate EHPs, emissions are lower than natural gas heating in 48% of census tracts; with current 90th percentile state-of-the-art EHPs, computed emissions are lower than natural gas heating in 67% of the census tracts. Because these census tracts tend to be in warmer locations, these census tracts represent 36% and 59% of total residential space heating, respectively. Another consideration is, of course, cost, and here we are only referring to the cost of electricity used for operating the EHPs. In some of these census tracts where GHG emissions are lower with EHPs, the heating costs are higher when compared to natural gas. Census tracts where we compute both emissions reductions and cost reductions with median cold climate EHPs represent 16% of all heating. With the state-of-the-art EHPs, this figure jumps to 48%. This suggests that heating electrification can already be a cost-effective means of reducing GHG emissions in some locations even with current levels of renewable energy and EHP technology.

Discussion

The computations presented in this report provide an understanding of the current contribution of space heating to residential building GHG emissions. The top line takeaways are clear: (1) Fossil fuel-based heating has lower emissions and energy costs than electric resistance heating, (2) among fossil fuels natural gas is both the lowest emission and least cost option, and (3) electric heat pumps (EHPs) are already the lowest emission and lowest energy cost heating option in nearly half the census tracts of the country, even with current electricity grid emissions (i.e. without additional renewable energy) and prices.

We note again here that we have not considered the capital costs or maintenance costs of any system whether new or replaced, and nor have we considered the costs associated with changing any distribution or delivery modalities. In this report, we discuss the several prominent approaches in current use and their associated roles in current emissions and their potential for reducing emissions.

The findings here are not necessarily novel, but they do help understand the context in which deep emissions reductions to the tune of 80% and approaching 100% will be necessary to mitigate the effects of climate change. This will frame the quantitative analysis of pathways to deep decarbonization of residential space heating that we will investigate in a later report. There are multiple options for this pathway, such as switching from propane and oil to natural gas (and extending gas infrastructure to where it does not yet reach), replacing electric resistance heating with EHPs, and in some prioritized fashion switching from fossil fuels (oil, propane and natural gas) to EHPs. Another option is maintaining fossil fuel equipment in dual source systems in some settings during a transition. These choices come with their own costs to the consumer, potential changes to distribution networks and aggregated societal impact on emissions.

As a flavor of those discussions, consider a switch of fuel oil or propane to natural gas, which has already been under way. Natural gas is frequently proposed as a "bridge fuel" towards an energy system that would eventually no longer rely on fossil fuels. We estimate that emissions reductions of a shift to natural gas could be significant for current fuel oil and propane users. This may not be an option for all as oil and propane might be the only fuel choices available. Extending natural gas infrastructure to less dense and rural areas could be extremely costly. Deploying costly new gas infrastructure only to be abandoned – if it is truly a bridge fuel – could saddle the users directly or indirectly with high costs. On the scale of the aggregate emission reductions, since less than 12% of homes use fuel oil or propane, the overall residential space heating emissions reduction would be only 4% even if all fuel oil and propane homes switched to natural gas.

Even with the advent of EHPs, this report highlights continued significant use of electric resistance heat especially in geographies where there is relatively low heating demand (Southeast) or inexpensive low-emission electricity (Northwest). This locational consideration is important for a shift to EHPs. We estimate that if all homes that use electric resistance heat were to shift to median performance EHP technologies, then the space heating emissions across the electric resistance group could be reduced by 70%. The overall residential space heating emissions reduction would be 27% with the current electricity grid. While this is certainly significant, the much larger emissions reductions needed motivate identifying changes that can occur at scale both within buildings and in broader energy systems, as well as the overall integrated performance of parallel building- and infrastructure-scale evolutions. We will investigate how this may be achieved, quantify its impact and assess approaches to *transition* away from the current system in a subsequent report.

Additional Resources, Data Sets and Acknowledgements

Joule **(**Feb 2019) **Paper**, **Data** The authors acknowledge the support of the National Science Foundation SRN Program Award # 1444745 (Drs. A. Ramaswami and P. Culligan SRN leads) and the Quadracci Sustainable Engineering Laboratory.

References

[1] U.S. Environmental Protection Agency (EPA). Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018. Washington D.C.: 2020.
[2] Waite M, Modi V. Electricity Load Implications of Space Heating Decarbonization Pathways. Joule 2020;4:376–94. doi:10.1016/j.joule.2019.11.011.
[3] U.S. Energy Information Administration (EIA). Natural Gas Prices. https://www.eia.gov/petroleum/heatingoilpropane/ (accessed January 3, 2020).
[4] U.S. Energy Information Administration (EIA). Heating Oil and Propane Update 2020.
[5] U.S. Energy Information Administration (EIA). Annual Energy Outlook 2019 with projections to 2050. Washington, DC: 2019.
[6] U.S. Census Bureau. 2017 American Housing Survey n.d. https://www.census.gov/programs-surveys/ahs/data/interactive/ahstablecreator.html (accessed April 3, 2020).
[7] United States Enivronmental Protection Agency (EPA). eGRID 2016 Summary Tables. 2018.
[8] United States Enivronmental Protection Agency (EPA). EnergyStar. 2012.
[9] Northeast Energy Efficiency Partnerships (NEEP). Northeast Energy Efficiency Partnerhips Cold Climate Air Source Heat Pump Product Listing, 2.15.2019
[10] Oak Ridge National Laboratory (ORNL), Los Alamos National Laboratory (LANL), Idaho National Laboratory (INL), National Geospatial-Intelligence Agency (NGA) Homeland Security Infrastructure Program (HSIP) Team. [Dataset] North American Electric Reliability Corporation (NERC) Regions and Subregions Shape Files 2019.
[11] De Chalendar JA, Taggart J, Benson SM. Tracking emissions in the US electricity system. Proc Natl Acad Sci 2019;116:25497–502. doi:10.1073/pnas.1912950116.

Appendix

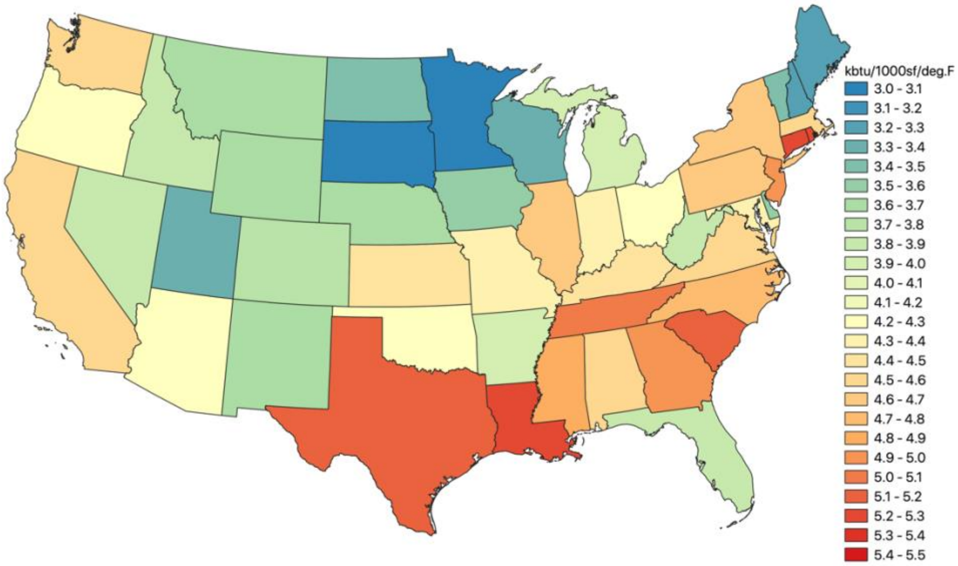


Figure A1 | Space heating energy temperature-dependence per 1000 sf floor areas. As computed in [2]. Temperature-dependence is relative to the 65°F reference temperature.

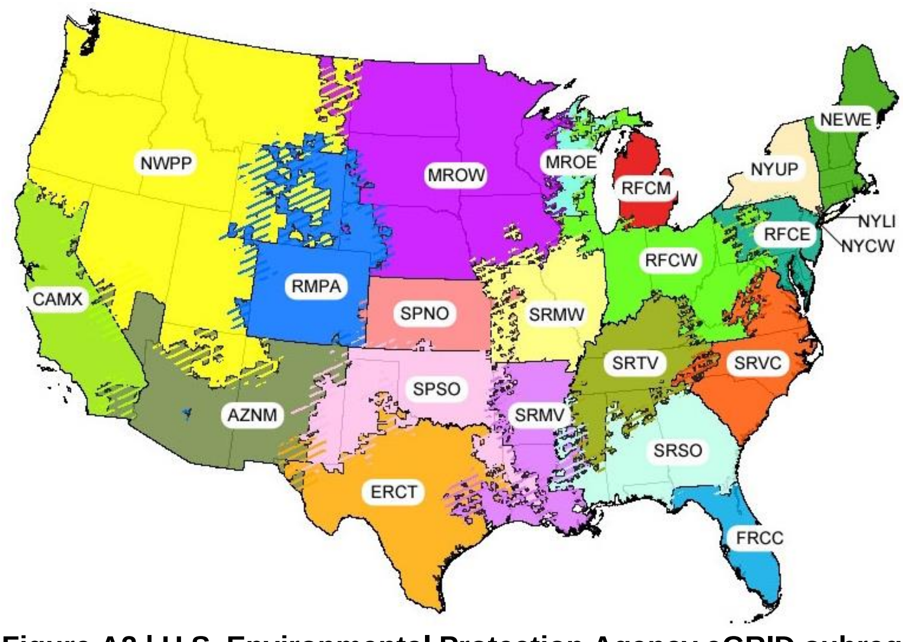


Figure A2 | U.S. Environmental Protection Agency eGRID subregions [7] Note: The boundaries of many subregions can overlap with others. Here we use the boundaries defined by publicly available shape files [10].

Table A1 | Average Residential Fossil Fuel Prices by State

State Name	State Abbreviation	Fuel Price ($/MMBtu)		
		Natural Gas	Fuel Oil	Propane
Alabama	AL	14.69	20.98[1]	28.09
Arizona	AZ	14.82	23.56[2]	26.47[2]
Arkansas	AR	11.36	20.98[1]	23.89
California	CA	11.87	23.56[2]	26.47[2]
Colorado	CO	7.45	23.56[2]	23.15
Connecticut	CT	13.44	24.12	32.58
Delaware	DE	12.16	22.76	34.44
District of Columbia	DC	11.37	29.42	35.20[1]
Florida	FL	20.60	20.98[1]	52.31
Georgia	GA	13.49	20.98[1]	25.40
Idaho	ID	6.86	23.56[2]	26.91
Illinois	IL	7.87	19.36[1]	17.88
Indiana	IN	8.42	20.04	22.39
Iowa	IA	8.63	17.85	14.54
Kansas	KS	9.83	19.36[1]	16.87
Kentucky	KY	10.19	19.40	24.34
Louisiana	LA	11.25	20.98[1]	26.78[1]
Maine	ME	15.75	21.93	32.79
Maryland	MD	11.38	23.53	35.81
Massachusetts	MA	14.93	23.79	34.28
Michigan	MI	7.91	19.53	22.06
Minnesota	MN	8.39	19.38	17.73
Mississippi	MS	10.02	20.98[1]	27.66
Missouri	MO	10.00	19.36[1]	19.36
Montana	MT	7.07	23.56[2]	20.71
Nebraska	NE	8.24	18.40	14.68
Nevada	NV	8.92	23.56[2]	26.47[2]
New Hampshire	NH	14.82	22.67	35.90
New Jersey	NJ	8.77	24.02	42.07
New Mexico	NM	7.62	23.56[2]	26.47[2]
New York	NY	11.94	25.76	35.78
North Carolina	NC	11.69	21.01	30.89
North Dakota	ND	6.95	19.36[1]	15.57
Ohio	OH	8.78	19.57	29.22
Oklahoma	OK	8.93	19.36[1]	20.93
Oregon	OR	10.28	23.56[2]	26.47[2]
Pennsylvania	PA	10.86	20.90	33.20
Rhode Island	RI	15.11	24.43	38.74
South Carolina	SC	13.06	20.98[1]	35.30[1]
South Dakota	SD	7.39	19.36[1]	16.23
Tennessee	TN	9.14	19.36[1]	33.00
Texas	TX	11.02	20.98[1]	26.65
Utah	UT	8.73	23.56[2]	27.84
Vermont	VT	13.18	20.80	37.88
Virginia	VA	11.30	20.96[1]	33.90
Washington	WA	9.92	23.56[2]	26.47[2]
West Virginia	WV	9.50	20.98	35.15[1]
Wisconsin	WI	7.76	19.59	17.20
Wyoming	WY	8.30	23.56[2]	23.73[1]
U.S. Average	*US*	*10.14*	*23.56*	*26.47*

[1]PADD or PADD subregion value (state-level data unavailable)
[2]U.S. average value (PADD or PADD subregion value unavailable)

Table A2 | Average Residential Electricity Price by eGRID Subregion

Subregion	Electricity Price

	$/kWh	$/MMBtu
AZNM	0.1243	36.43
CAMX	0.1874	54.92
ERCT	0.0984	28.84
FRCC	0.1065	31.21
MROE	0.1339	39.24
MROW	0.1126	33.00
NEWE	0.1864	54.63
NWPP	0.0992	29.07
NYCW	0.2461	72.12
NYLI	0.2180	63.89
NYUP	0.1239	36.31
RFCE	0.1374	40.27
RFCM	0.1498	43.90
RFCW	0.1321	38.71
RMPA	0.1339	39.24
SPNO	0.1419	41.59
SPSO	0.1013	29.69
SRMV	0.1013	29.69
SRMW	0.1268	37.16
SRSO	0.1225	35.90
SRTV	0.1007	29.51
SRVC	0.1136	33.29
US	0.1250	36.63