Energy and Emissions from US Population Shifts and Implications for Regional GHG Mitigation Planning - Supplementary Information

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1 Emission Factors

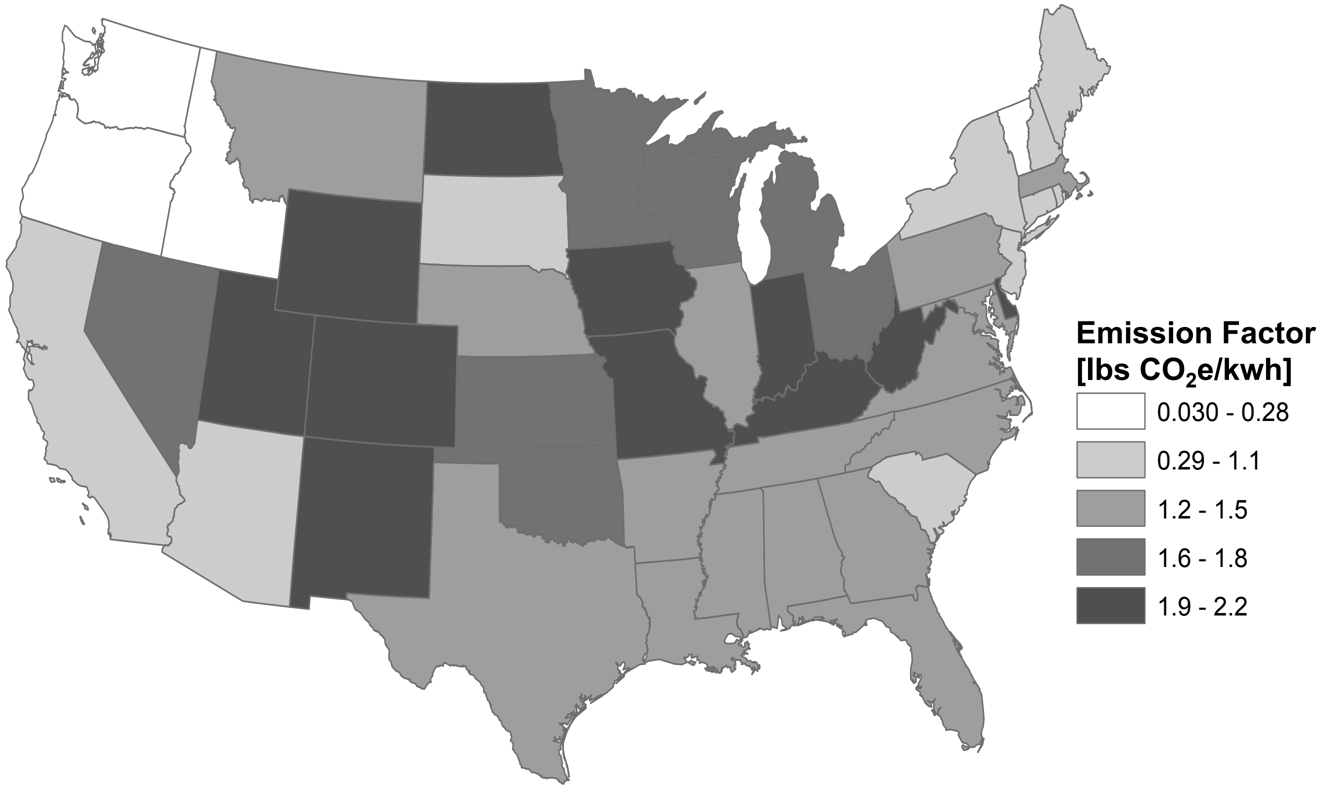


Figure 1 State electricity emission factors estimated by EIA's Voluntary Reporting Green house Gasses Program[1]

Table 1 Average Electricity Emission Factors (lbs CO_2eq/kWh) by state and region from EIA's Voluntary Reporting of Greenhouse Gases Program[1]

State	Region	State Emission Factor	Region Average Emission Factor
Alabama	East-South Central	1.32	1.50
Alaska	Pacific Non-contiguous	1.38	1.56
Arizona	Mountain	1.05	1.57
Arkansas	West-South Central	1.30	1.43
California	Pacific Contiguous	0.61	0.45
Colorado	Mountain	1.94	1.57
Connecticut	New England	0.94	0.98
Delaware	South Atlantic	1.84	1.36
District of Columbia	South Atlantic	1.38	1.36
Florida	South Atlantic	1.40	1.36
Georgia	South Atlantic	1.38	1.36
Hawaii	Pacific Non-contiguous	1.67	1.56
Idaho	Mountain	0.03	1.57
Illinois	East-North Central	1.17	1.64
Indiana	East-North Central	2.09	1.64
Iowa	West-North Central	1.89	1.74
Kansas	West-North Central	1.69	1.74
Kentucky	East-South Central	2.02	1.50
Louisiana	West-South Central	1.18	1.43
Maine	New England	0.86	0.98
Maryland	South Atlantic	1.38	1.36

Massachusetts	New England	1.29	0.98
Michigan	East-North Central	1.59	1.64
Minnesota	West-North Central	1.53	1.74
Mississippi	East-South Central	1.30	1.50
Missouri	West-North Central	1.85	1.74
Montana	Mountain	1.44	1.57
Nebraska	West-North Central	1.41	1.74
Nevada	Mountain	1.53	1.57
New Hampshire	New England	0.68	0.98
New Jersey	Mid Atlantic	0.71	1.04
New Mexico	Mountain	2.03	1.57
New York	Mid Atlantic	0.86	1.04
North Carolina	South Atlantic	1.25	1.36
North Dakota	West-North Central	2.25	1.74
Ohio	East-North Central	1.81	1.64
Oklahoma	West-South Central	1.73	1.43
Oregon	Pacific Contiguous	0.28	0.45
Pennsylvania	Mid Atlantic	1.27	1.04
Rhode Island	New England	1.05	0.98
South Carolina	South Atlantic	0.83	1.36
South Dakota	West-North Central	0.80	1.74
Tennessee	East-South Central	1.31	1.50
Texas	West-South Central	1.46	1.43
Utah	Mountain	1.94	1.57
Vermont	New England	0.03	0.98
Virginia	South Atlantic	1.17	1.36
Washington	Pacific Contiguous	0.25	0.45
West Virginia	South Atlantic	1.99	1.36
Wisconsin	East-North Central	1.65	1.64
Wyoming	Mountain	2.16	1.57

Table 2 Life Cycle Natural Gas Emission Factors

Source	Emission Factor
Venkatesh et al[2,3]	66 g CO_2eq/MJ $\times\frac{lb\ CO2eq}{453.59g}\times\frac{1055.87MJ}{MMBTU}$ = 153 lb CO_2eq/MMBtu
Advanced resources international[2,4]	145 lb CO_2eq/MMBtu
NREL US Lifecycle Inventory Database[4]	148 lb CO_2eq/MMBtu
Average Emission Factor	149 lb CO_2eq/MMBtu

Table 3 Other Residential Fuel Emission Factors from NREL Lifecycle Inventory Database[4]

Fuel	**Emission Factor**
Fuel Oil	192 CO_2eq/MMBtu
Kerosene	190 CO_2eq/MMBtu
Propane (LPG)	155 CO_2eq/MMBtu

2 Supplementary Results and Figures

2.1 Residential Energy

2.1.1 Electricity vs Residential Fuels

Comparisons of distribution figures that reflect only electricity emissions versus those that reflect all residential fuels illustrate the same conclusion. In figures reflecting only electricity emissions for Florida, many of distribution curves are skewed and peak to the right of zero, because Florida has a carbon intense electricity grid, especially in comparison to Northeast states (shown in pink)- the origin of many migration households. However, the addition of natural gas and other residential fuels makes the curves narrower and centered about zero, illustrating that emissions from other fuels mute the emissions changes from electricity that households experience when moving across states.

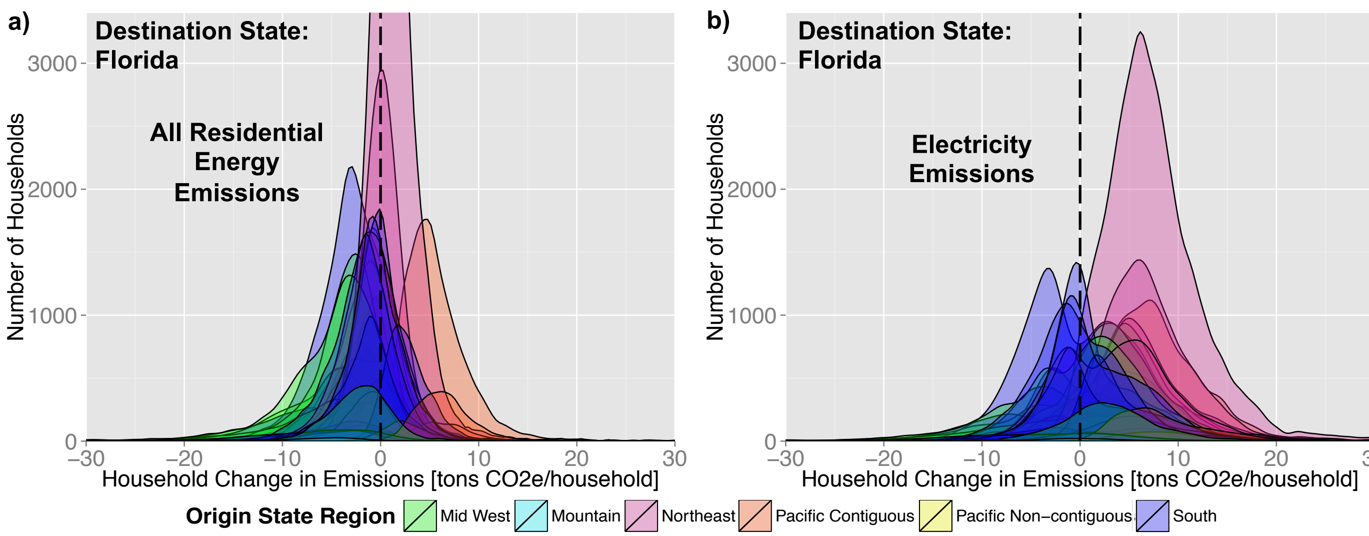
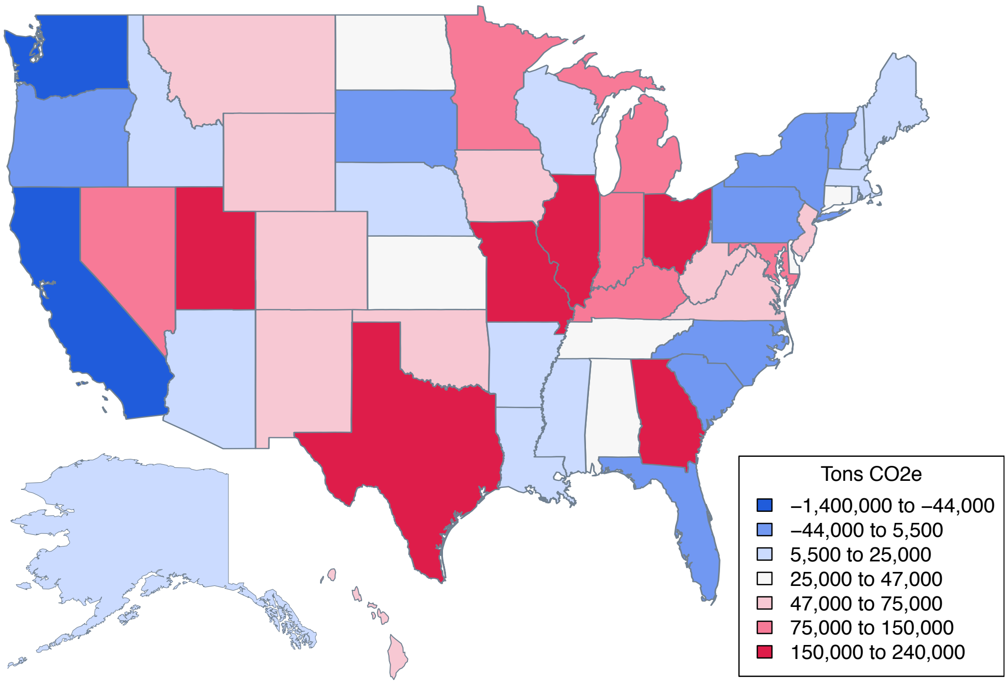
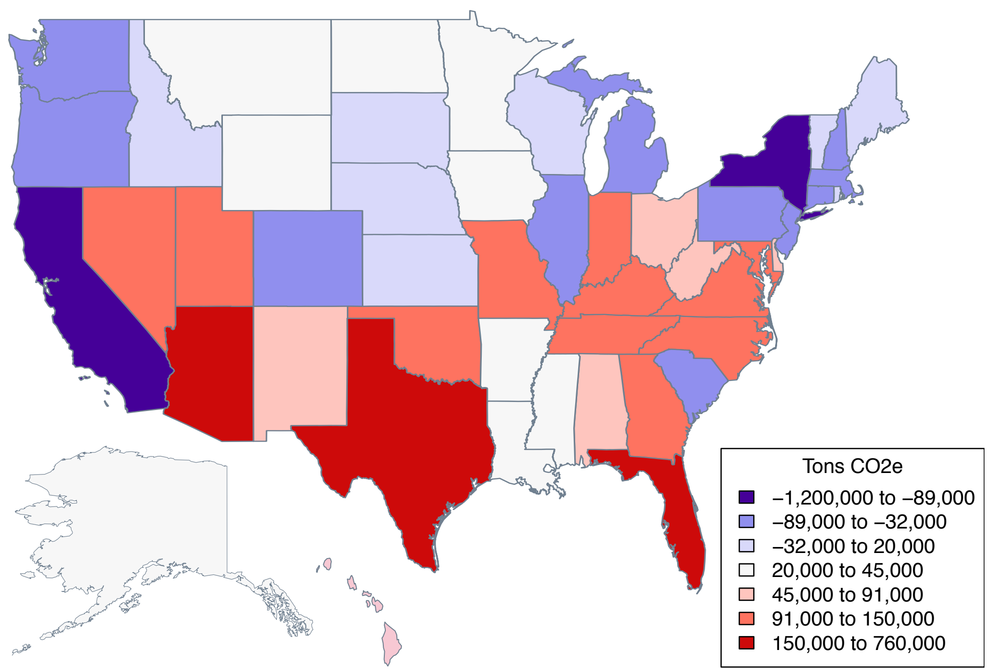


Figure 2 The distributions of expected changes in (a) all residential emissions and (b) electricity emissions for households moving to Florida. Emissions changes are driven by differences in electricity emissions, but dampened by the addition of emissions from other residential fuels.



a)



b)

Figure 3 Sum of expected residential emission changes for all households migrating to each state for a) residential emissions from all residential fuels (electricity, natural gas, fuel oil, kerosene, and propane) and b) only residential electricity emissions

2.1.2 Region Radial Diagrams

Figure 4 and Figure 5 show the emission changes for migration flows between US Census Regions. Figure 4 shows the flows that sum to net emissions increases and Figure 5 shows the flows that sum to net emissions decreases. US census regions are organized around the outside of the circle. Lines connecting each region represent the sum of residential emissions for all households moving between those regions. The width of connecting lines represent the size of the emissions sum and are colored by origin Census Region.

Figure 4, which shows the US census region flows that sum to net emissions increases, is dominated by households moving from the Pacific region, which includes California and the Pacific Northwest, to every other US census region. The largest regional flow, shown in pink, represents households moving from the Pacific-contiguous region to the Mountain region. This flow mostly consists of households moving from California to Arizona and Nevada. Emissions flows from the Pacific region are mostly dominated by many households leaving California and experiencing moderate emissions increases. Figure 4 shows no flows terminating in the Pacific region, because all regional flows to the Pacific region sum to net emissions decreases.

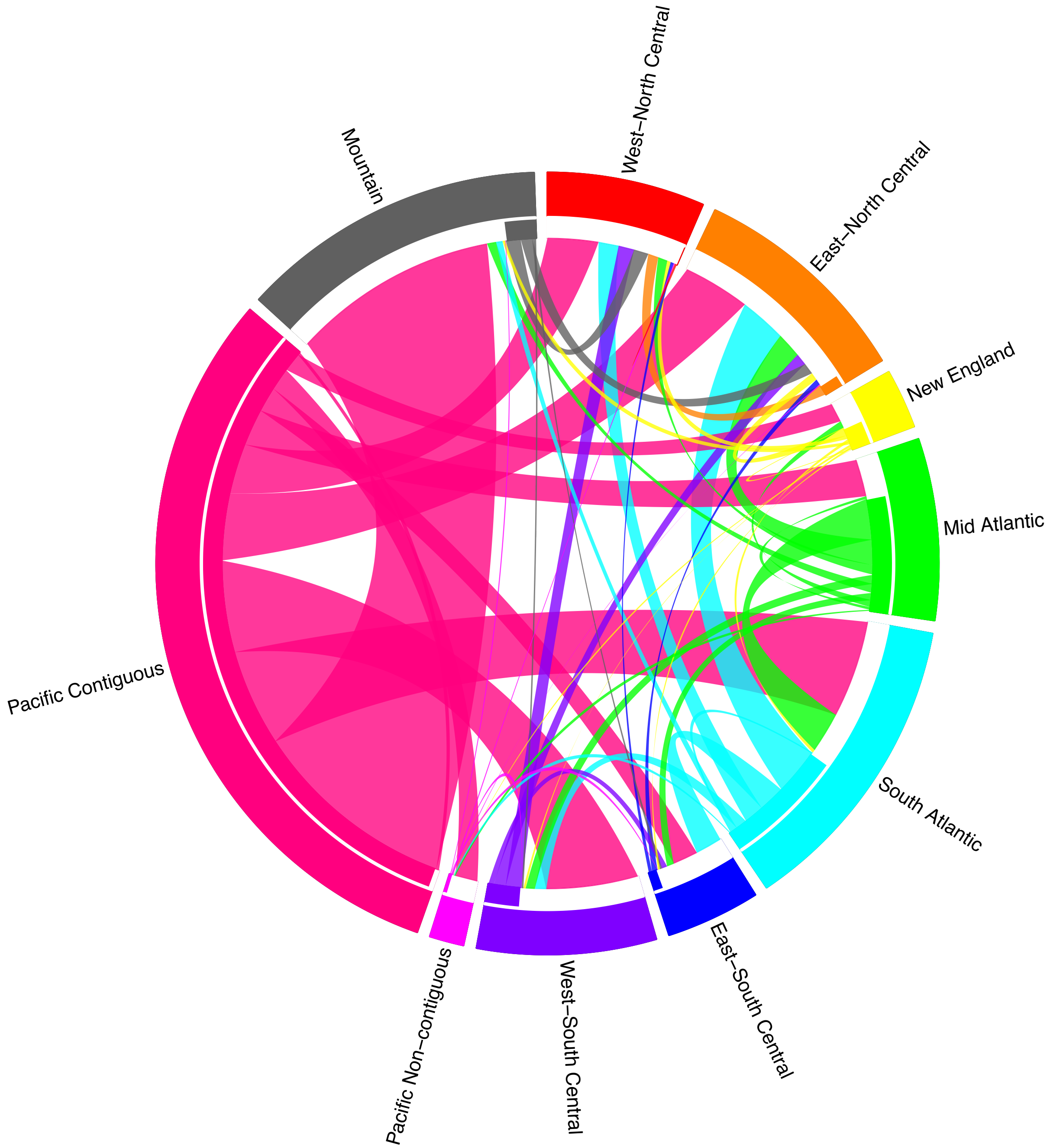


Figure 4 Radial migration diagram showing the sums of residential emissions changes for flows between US Census Regions that sum to net positive emissions, or emissions increases. Flows between regions representing emissions decreases are shown in Figure 5. The width of connecting lines represent the size of the emissions sum for all households in that flow and are colored by origin census region.

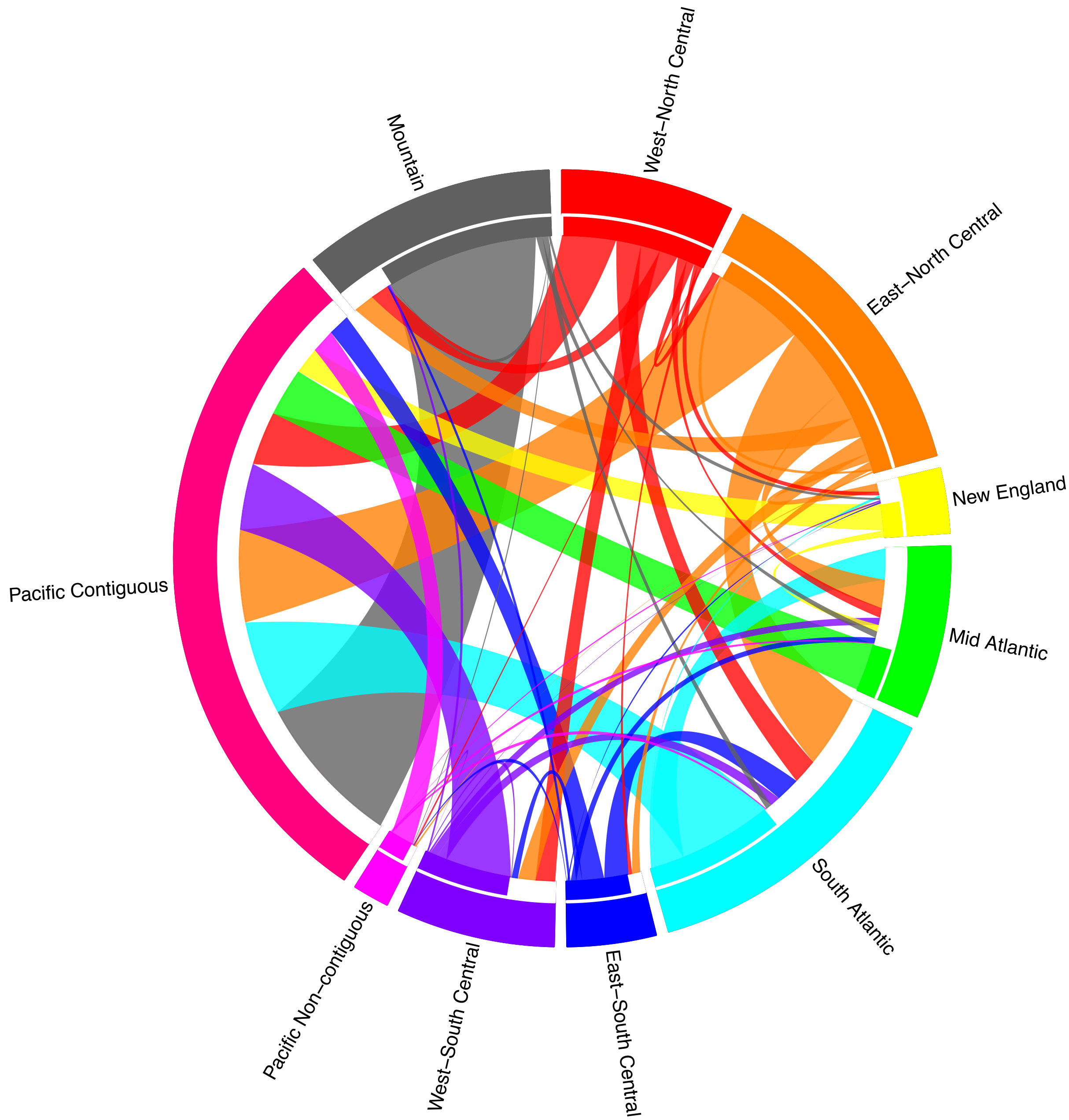


Figure 5 Radial migration diagram showing the sums of residential emissions changes for flows between US Census Regions that sum to net negative emissions, or emissions decreases. Flows between regions representing emissions increases are shown in Figure 4. The width of connecting lines represent the size of the emissions sum for all households in that flow and are colored by origin census region.

Figure 5, which shows region flows that sum to net emissions decreases, is dominated by households moving from other US census regions to the Pacific Region. Because total emissions changes in the US net close to zero, the sum of emissions in Figure 4 and is roughly equal to the sum of emissions in Figure 5. Therefore, the width of the lines representing emissions flows in both figures is comparable.

2.1.3 Residential Emissions Change Distributions by Origin State

Similar to figure 2 in the main text, these figures shows the distributions of household emissions changes for all household moving to a destination state by origin states, colored by census region. Some figure cut off the tops of curves of very large migration flows. Figure shows the distributions of the changes in household emissions for all households moving to Arkansas by origin state. The 50 curves in the figure represent the 79,000 households moving to Colorado from the other 49 states and DC, colored by US Census Region. The figure shows the regional nature of migration flows and the similarity of state household emission profiles for geographically close states. Many curves peak at or close to zero. However, curves representing origin states in the mountain region, shown in turquoise, are shifted slightly left, indicating that households often emit less emissions when living in Colorado than in other mountain states, while curves representing origin states in the Pacific regions are shifted right - indicating that households often emit more emissions when living in Colorado than in Pacific states. The 5^{th} and 95^{th} percentile of emission changes for all households moving to Colorado is -7.4 and 11.8 tons CO_2eq/household/year respectively, but the overall range is from -25 to +30 tons CO_2eq/household/year.

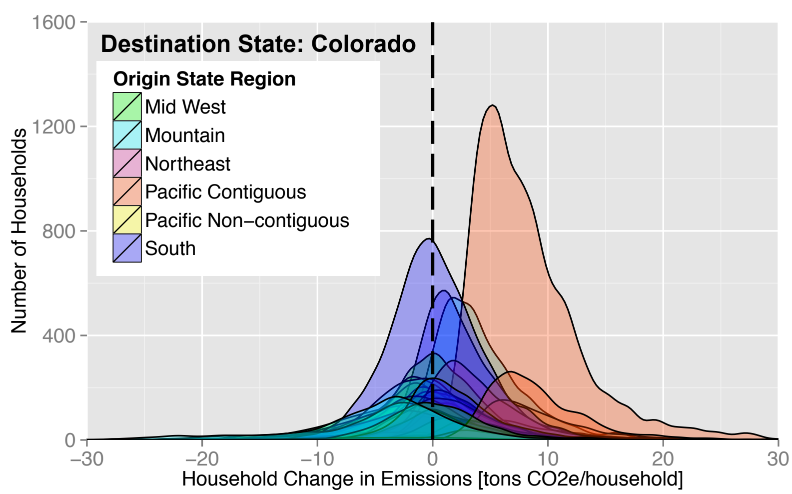


Figure 6 The distributions of expected change in residential emissions for all households moving to Colorado. Each curve is the distribution for households moving from 49 other states and DC (origin state) to Colorodo (destination state), colored by origin state Census region.

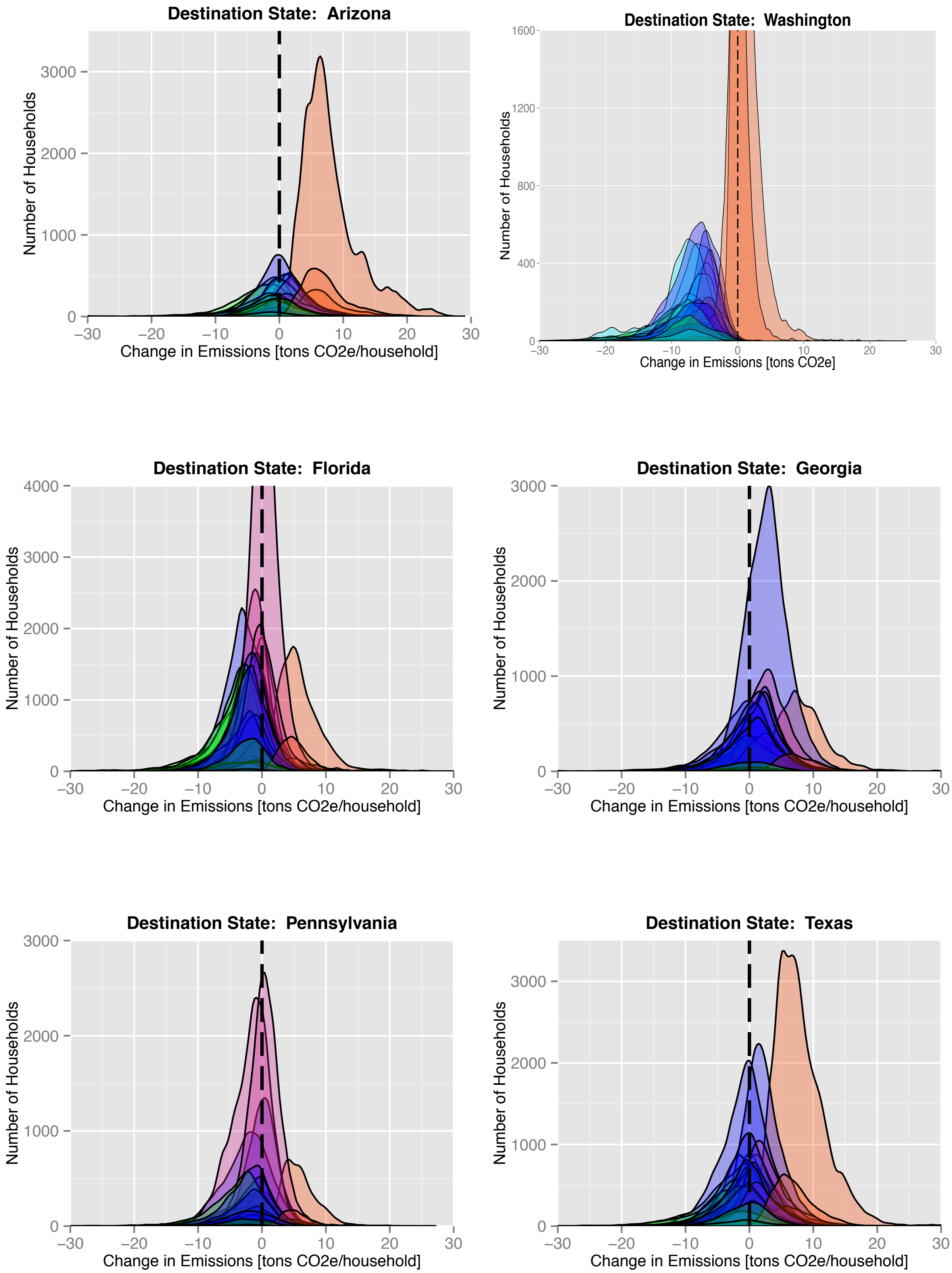


Figure 7 Similar to Figure 6. Distributions of residential emission changes for select destination states.

2.1.4 Size and Emissions of Select flows

Table 1 Net residential emission changes and size of migration flow for 6 largest flows and 6 largest emission sums

	Largest Flows			Largest Emission Sum	
Flow	**Flow Size [Households]**	**Emission Sum [tons CO_2eq]**	**Flow**	**Emission Sum [tons CO_2eq]**	**Flow Size [Households]**
NY to FL	31,912	18,400	**CA to TX**	224,300	28,250
CA to TX	28,250	224,300	**CA to AZ**	194,000	24,297
NY to NJ	27,856	60,300	**TX to CA**	-136,600	17,304
CA to AZ	24,297	194,000	**AZ to CA**	-113,200	14,090
FL to GA	22,761	57,900	**CA to CO**	78,500	10,786
CA to NV	21,141	158,200	**NY to CA**	-75899	13,703

2.2 Transportation Emissions

2.2.1 State Flows

Table 4 Average VMT and Transportation Emissions per HH in 2005 and 2010, by state

State	VMT per HH 2005	VMT per HH 2010	Transportation CO_2eq 2005 [tons/hh]	Transportation CO_2eq 2010 [tons/hh]	Change from 2005 to 2010 [tons/HH]
Alabama	33,350	35,350	17.49	17.58	0.1
Alaska	21,590	18,840	11.32	9.37	-1.9
Arizona	27,130	25,730	14.23	12.80	-1.4
Arkansas	29,400	30,050	15.42	14.95	-0.5
California	27,220	26,020	14.27	12.94	-1.3
Colorado	26,370	23,940	13.83	11.91	-1.9
Connecticut	23,930	23,030	12.55	11.46	-1.1
Delaware	29,930	27,220	15.70	13.54	-2.2
District of Columbia	14,960	14,230	7.84	7.08	-0.8
Florida	28,590	27,830	14.99	13.84	-1.2
Georgia	34,190	32,080	17.93	15.96	-2.0
Hawaii	23,450	22,420	12.30	11.15	-1.1
Idaho	27,940	27,400	14.65	13.63	-1.0
Illinois	22,960	22,260	12.04	11.07	-1.0
Indiana1	29,390	30,660	15.41	15.25	-0.2
Iowa	25,870	25,660	13.56	12.76	-0.8
Kansas	27,630	27,140	14.49	13.50	-1.0
Kentucky	28,700	28,500	15.05	14.18	-0.9
Louisiana	26,830	26,890	14.07	13.38	-0.7
Maine	27,530	26,680	14.44	13.27	-1.2
Maryland	27,000	26,380	14.16	13.12	-1.0
Massachusetts	22,650	21,570	11.88	10.73	-1.2
Michigan	26,760	25,630	14.03	12.75	-1.3

Minnesota	28,170	27,080	14.77	13.47	-1.3
Mississippi	38,920	36,890	20.41	18.35	-2.1
Missouri	30,090	30,150	15.78	15.00	-0.8
Montana	30,210	27,780	15.84	13.82	-2.0
Nebraska	27,730	27,020	14.54	13.44	-1.1
Nevada	22,910	21,340	12.02	10.61	-1.4
New Hampshire	27,020	25,350	14.17	12.61	-1.6
New Jersey	23,490	23,020	12.32	11.45	-0.9
New Mexico	32,930	33,100	17.27	16.46	-0.8
New York	19,330	18,240	10.14	9.07	-1.1
North Carolina	29,700	27,890	15.57	13.87	-1.7
North Dakota	27,990	29,470	14.68	14.66	0.0
Ohio	24,510	24,710	12.85	12.29	-0.6
Oklahoma	34,060	33,320	17.86	16.57	-1.3
Oregon	24,750	22,410	12.98	11.15	-1.8
Pennsylvania	22,230	20,330	11.66	10.11	-1.5
Rhode Island	20,440	20,580	10.72	10.24	-0.5
South Carolina	30,220	27,890	15.85	13.87	-2.0
South Dakota	27,060	27,800	14.19	13.83	-0.4
Tennessee	29,930	28,860	15.69	14.36	-1.3
Texas	29,480	26,780	15.46	13.32	-2.1
Utah	31,770	30,210	16.66	15.03	-1.6
Vermont	31,000	28,210	16.26	14.03	-2.2
Virginia	27,800	27,460	14.58	13.66	-0.9
Washington	22,640	21,940	11.87	10.91	-1.0
West Virginia	27,710	25,880	14.53	12.87	-1.7
Wisconsin	27,040	26,070	14.18	12.97	-1.2
Wyoming	44,200	42,940	23.18	21.36	-1.8
United States, total	26,910	25,890	14.11	12.88	-1.2

2.2.2 Region Flows

Table 5 shows the sum of emissions changes for migration flows between US census regions. These emission sums represent the sum of transportation emission changes for all households in state-to-state flows encompassed by a US census region. For example, household moving for California to Colorado and California to Arizona are both represented in the Pacific to Mountain region flow, while households moving from California to Georgia are represented in the Pacific to South Atlantic region flow. Households moving from state to state within the same region are represented in flows along the diagonal. For example, households moving from Arizona to Colorado are represented in the Mountain-Mountain region flow. Region flow emission sums vary from -354,000 tons CO_2eq (households moving from the South Atlantic to the Mid Atlantic) to 606,000 tons CO_2eq for the opposite flow (households moving from the Mid Atlantic to the South Atlantic). Emissions increases are greatest for households moving to the South Atlantic, which includes high transportation emission states like Georgia and Florida; these emissions sum to more than 1,040,000 tons CO_2eq. The largest emissions decreases come from households moving to the Mid Atlantic, which sum to -690,000 tons CO2eq. While residential emissions changes are dominated by households moving to and from the Pacific region, transportation emission changes are more balanced over census regions.

Table 5 Net household transportation emission sums for flows between US Census Regions. Emission sums represent the sum of household emissions changes for all households in the state - state flows encompassed in a region flow. Migration flows are from origin census region (row) to destination census region (column).

Origin Census Region	Destination Census Region									
	West-North Central	East-North Central	New England	Mid Atlantic	South Atlantic	East-South Central	West-South Central	Pacific Non-contiguous	Pacific Contiguous	Mountain
West-North Central	2,050	-55,000	-7,180	-29,200	11,800	12,900	27,600	-6,350	-23,700	7,770
East-North Central	63,300	8,240	-6,370	-56,700	183,000	84,400	72,000	-4,740	14,900	38,900
New England	7,060	5,070	7,960	-53,300	118,000	12,600	19,800	-1,150	19,400	15,300
Mid Atlantic	29,200	51,000	60,000	18,900	606,000	49,300	80,600	2,100	88,700	61,700
South Atlantic	-11,100	-122,000	-68,300	-354,000	45,700	49,300	-1,170	-22,500	-72,200	-26,500
East-South Central	-12,600	-59,200	-9,220	-36,600	-45,800	-75	-55,700	-7,060	-28,200	-17,000
West-South Central	-21,900	-47,700	-14,100	-60,700	6,910	55,400	8,460	-13,500	-59,500	-21,800
Pacific Non-contiguous	5,840	3,500	922	-1,760	22,500	6,910	14,900	0	16,300	17,200
Pacific Contiguous	20,900	-13,000	-14,300	-73,500	75,200	31,500	77,900	-17,000	-21,800	52,000
Mountain	-6,780	-24,600	-10,600	-42,400	22,400	16,400	25,200	-15,300	-57,400	2,120

2.3 Total Household Emissions

Table 6 Residential and Transportation Emission Changes for Migrating Household. The Sum of Emissions Changes, in tons CO_2eq for all households moving to each state. Residential Energy results reflect Average of State and regional emissions factors and the BTU method of modeling Household energy use.

	Residential Energy	Transportation	Total Household		Residential Energy	Transportation	Total Household
ALABAMA	64,900	126,000	191,000	**MONTANA**	51,400	16,500	67,900
ALASKA	22,700	-48,600	-25,900	**NEBRASKA**	29,600	2,210	31,800
ARIZONA	212,000	1,840	214,000	**NEVADA**	152,000	-130,000	22,700
ARKANSAS	16,300	20,900	37,200	**NEW HAMPSHIRE**	14,900	16,400	31,300
CALIFORNIA	-1,550,000	107,000	-1,450,000	**NEW JERSEY**	110,000	5,420	115,000
COLORADO	21,100	-81,900	-60,800	**NEW MEXICO**	22,100	95,000	117,000
CONNECTICUT	27,900	-3,870	24,100	**NEW YORK**	-185,000	-495,000	-680,000
DELAWARE	18,600	30,700	49,300	**NORTH CAROLINA**	-29,200	156,000	127,000
DISTRICT OF COLUMBIA	23,800	-146,000	-123,000	**NORTH DAKOTA**	19,700	6,330	26,100
FLORIDA	-347,000	306,000	-41,000	**OHIO**	160,000	-80,600	79,200
GEORGIA	172,000	378,000	550,000	**OKLAHOMA**	34,100	123,000	157,000
HAWAII	57,100	-39,500	17,600	**OREGON**	-188,000	-56,400	-244,000
IDAHO	114,000	16,900	131,000	**PENNSYLVANIA**	-126,000	-193,000	-320,000
ILLINOIS	321,000	-222,000	98,700	**RHODE ISLAND**	10,800	-22,700	-11,900
INDIANA	76,100	107,000	183,000	**SOUTH CAROLINA**	-23,000	62,400	39,400
IOWA	65,100	-12,200	52,900	**SOUTH DAKOTA**	25,300	-814	24,500
KANSAS	45,800	-14,200	31,600	**TENNESSEE**	91,700	40,200	132,000
KENTUCKY	36,500	27,500	64,000	**TEXAS**	203,000	93,200	296,000
LOUISIANA	32,700	-38,600	-5,920	**UTAH**	113,000	69,200	182,000
MAINE	7,330	13,200	20,500	**VERMONT**	6,150	23,700	29,800
MARYLAND	84,700	83,400	168,000	**VIRGINIA**	124,000	103,000	227,000
MASSACHUSETTS	-39,000	-87,000	-126,000	**WASHINGTON**	-402,000	-173,000	-575,000
MICHIGAN	104,000	-12,100	91,600	**WEST VIRGINIA**	8,150	2,780	10,900
MINNESOTA	113,000	23,400	136,000	**WISCONSIN**	-15,300	9,400	-5,950
MISSISSIPPI	30,300	145,000	175,000	**WYOMING**	25,800	108,000	133,000
MISSOURI	205,000	99,500	304,000	**UNITED STATES**	165,000	561,000	725,000

3 Supplementary Discussion of Limitations and Uncertainty

3.1 Electricity Emission Factors

3.1.1 State versus Regional Emissions Factor Estimates

Table 7 Summary Statistics for distributions of Household Emission change per year, by destination state, using state, regional, and average of state and regional Electricity Emission Factors, measured in tons CO_2e. States that exhibit larger differences are highlighted.

	Median			Mean			5%			95%			Sum of Emissions Changes		
State Name	**Average**	**State**	**Regional**	**Average**	**State**	**Regional**	**Average**	**State**	**Regional**	**Average**	**State**	**Regional**	**Average**	**State**	**Regional**
Alabama	0.9	0.6	1.5	0.8	0.3	1.4	-6.9	-7.4	-6.6	8.3	7.7	9.4	37,100	15,700	63,100
Alaska	0.8	0.5	1.0	1.2	0.8	1.5	-8.0	-8.6	-7.5	11.5	10.8	12.1	17,700	11,500	22,500
Arizona	0.1	-1.4	1.8	0.2	-1.6	2.1	-8.7	-10.6	-7.0	8.9	6.2	12.2	22,600	-163,000	210,000
Arkansas	0.1	-0.2	0.4	0.1	-0.4	0.5	-8.6	-9.3	-7.9	8.8	8.2	9.7	2,760	-11,800	16,900
California	-6.2	-5.7	-6.7	-6.9	-6.3	-7.4	-15.3	-15.0	-15.9	0.3	1.1	-0.4	-1,450,000	-1,340,000	-1,560,000
Colorado	0.7	1.5	0.0	1.1	1.8	0.3	-7.5	-7.4	-8.0	10.5	11.8	9.2	85,100	142,000	21,500
Connecticut	0.8	0.9	0.8	0.9	0.9	0.8	-5.1	-5.3	-5.2	6.8	7.0	7.0	29,300	29,600	27,200
Delaware	2.6	4.0	1.2	3.0	4.6	1.3	-5.4	-4.6	-6.3	12.0	15.2	8.7	43,500	67,300	18,500
District of Columbia*	1.1	1.3	0.8	1.2	1.4	1.0	-7.0	-7.0	-7.0	9.7	9.6	9.4	30,500	33,700	25,100
Florida	-1.1	-0.8	-1.4	-1.2	-0.9	-1.4	-8.4	-8.5	-8.4	5.3	5.7	5.1	-286,000	-216,000	-349,000
Georgia	1.8	2.2	1.5	1.7	2.0	1.4	-6.1	-6.0	-6.4	9.4	9.8	9.1	206,000	243,000	172,000
Hawaii	2.3	2.9	1.9	3.0	3.4	2.5	-6.4	-6.5	-6.9	14.1	14.7	13.4	68,200	77,600	56,300
Idaho	1.2	-2.9	5.1	0.3	-4.1	4.8	-9.3	-15.4	-5.2	7.0	3.2	15.7	7,400	-98,800	116,000
Illinois	1.3	0.3	2.2	1.9	0.6	3.3	-7.2	-8.7	-5.9	12.6	10.5	15.1	187,000	62,600	318,000
Indiana	2.3	3.6	1.2	2.7	4.1	1.4	-7.0	-6.7	-7.7	13.9	16.4	11.4	151,000	226,000	77,200
Iowa	2.2	3.0	1.6	2.9	3.7	2.2	-6.3	-5.7	-7.2	14.8	16.2	13.8	85,700	109,000	64,800
Kansas	1.1	0.9	1.2	1.0	0.8	1.2	-8.9	-9.7	-8.4	10.8	10.7	11.0	36,600	29,400	44,400
Kentucky	2.9	4.8	1.1	2.8	4.7	0.9	-6.8	-6.1	-7.8	12.5	15.8	9.2	119,000	202,000	38,300
Louisiana	0.0	-0.6	0.7	0.0	-0.8	0.8	-7.5	-8.5	-7.1	7.8	6.6	9.3	324	-33,000	31,500
Maine	0.4	0.3	0.5	0.4	0.3	0.5	-5.6	-5.9	-5.4	6.3	6.3	6.7	4,930	3,840	6,920
Maryland*	1.2	1.3	1.1	1.2	1.3	1.2	-7.1	-7.3	-6.9	9.4	9.7	9.3	90,500	98,300	86,100
Massachusetts	0.0	0.7	-0.6	0.1	0.8	-0.6	-6.2	-5.9	-6.9	6.9	7.9	6.0	6,960	49,000	-40,100
Michigan	2.0	2.1	2.0	2.0	1.9	2.1	-6.5	-7.4	-6.4	10.9	10.7	11.0	102,000	95,300	107,000
Minnesota	1.7	1.4	2.0	2.2	1.8	2.7	-6.7	-7.7	-6.5	13.1	12.4	14.4	94,400	74,000	114,000
Mississippi	0.8	0.4	1.2	0.7	0.3	1.1	-7.0	-7.3	-6.9	8.1	7.3	9.2	20,200	7,430	32,900
Missouri	3.4	3.9	3.0	3.9	4.5	3.4	-5.5	-5.2	-6.0	15.2	16.1	14.4	237,000	271,000	204,000
Montana	3.0	3.3	3.0	3.2	3.1	3.3	-6.7	-7.8	-6.7	13.5	13.4	13.9	50,300	48,400	51,600
Nebraska	0.8	0.2	1.5	0.7	-0.2	1.6	-8.7	-10.0	-7.7	10.0	8.6	11.3	13,500	-2,960	30,500
Nevada	3.0	3.0	3.0	2.6	2.5	2.6	-6.7	-7.2	-7.1	11.7	11.3	12.1	152,000	144,000	151,000
New Hampshire	0.2	-0.4	0.7	0.1	-0.5	0.7	-5.4	-6.2	-4.8	5.4	5.1	6.3	2,170	-10,300	14,600

	Median			Mean			5%			95%			Sum of Emissions Changes		
State Name	**Average**	**State**	**Regional**	**Average**	**State**	**Regional**	**Average**	**State**	**Regional**	**Average**	**State**	**Regional**	**Average**	**State**	**Regional**
New Mexico	1.7	2.9	0.4	2.1	3.4	0.7	-6.4	-5.9	-7.6	11.6	14.0	9.3	63,800	101,000	21,400
New York	-1.3	-1.4	-1.2	-1.5	-1.7	-1.3	-8.1	-8.5	-8.0	5.0	4.7	5.4	-213,000	-241,000	-187,000
North Carolina	-0.1	-0.2	0.0	-0.4	-0.6	-0.2	-7.7	-8.2	-7.4	6.4	6.1	6.7	-49,200	-73,400	-26,600
North Dakota	2.8	4.5	1.4	3.7	5.6	2.0	-6.4	-4.9	-8.0	16.5	20.6	13.4	35,700	53,500	18,900
Ohio	2.2	2.7	1.9	2.5	2.9	2.2	-6.7	-7.6	-6.3	12.7	13.8	11.9	184,000	210,000	160,000
Oklahoma	1.8	2.8	0.7	2.0	3.1	0.8	-6.7	-6.1	-7.5	11.5	13.5	9.9	78,200	123,000	32,500
Oregon	-2.8	-2.7	-2.6	-3.9	-4.2	-3.6	-12.7	-13.6	-12.5	2.0	1.8	2.5	-201,000	-216,000	-188,000
Pennsylvania	-0.3	0.5	-1.0	-0.6	0.2	-1.3	-7.8	-7.8	-8.1	6.0	7.1	4.9	-54,700	17,400	-127,000
Rhode Island	0.8	0.9	0.8	0.9	1.0	0.9	-4.8	-4.8	-4.8	7.0	7.3	6.9	11,100	12,300	10,300
South Carolina	-1.7	-3.2	-0.1	-2.1	-3.9	-0.4	-9.0	-11.1	-7.4	3.7	1.6	6.2	-135,000	-245,000	-24,000
South Dakota	-0.3	-2.2	1.6	-0.2	-2.7	2.3	-9.5	-12.4	-7.7	8.9	5.6	14.0	-2,380	-31,400	26,200
Tennessee	0.5	0.1	1.0	0.5	-0.2	1.2	-7.4	-8.8	-6.7	8.7	7.7	9.8	39,900	-15,200	91,800
Texas	1.0	1.3	0.7	1.2	1.4	0.9	-7.2	-7.4	-7.4	10.0	10.3	9.9	244,000	289,000	200,000
Utah	4.7	6.2	3.2	5.2	6.7	3.7	-4.4	-3.9	-5.9	16.9	20.2	14.3	160,000	206,000	113,000
Vermont	-1.0	-2.6	0.5	-1.1	-2.9	0.6	-6.9	-9.4	-5.1	4.6	2.8	6.7	-10,100	-26,500	5,760
Virginia	0.5	0.0	1.0	0.4	-0.2	1.1	-7.3	-8.2	-6.5	8.3	7.4	9.4	50,500	-26,700	127,000
Washington	-4.8	-4.7	-4.6	-5.0	-5.3	-4.7	-13.6	-14.6	-13.4	1.4	1.1	2.0	-429,000	-457,000	-402,000
West Virginia	2.5	4.5	0.5	2.7	4.9	0.5	-6.6	-5.8	-7.8	12.6	17.1	8.5	49,700	91,600	8,460
Wisconsin	0.2	0.5	-0.1	0.0	0.4	-0.4	-8.9	-8.6	-9.7	8.6	8.9	8.4	562	16,300	-15,400
Wyoming	3.2	4.9	1.6	4.0	6.1	2.2	-5.8	-4.6	-7.3	16.8	21.2	12.6	51,100	76,900	27,300
												Sum	**98,400**	**31,400**	**153,000**

3.1.2 Average Emission Factors vs Marginal Emission Factors

Marginal emission factors (MEFs) have been used to estimate emissions savings of avoided electricity use from demand side-interventions. Unlike average emission factors (AEFs), like those used in this report, that measure the CO_2 content of grid average electricity, MEFs measure the emission intensities of additional electricity generators needed to meet electricity demand (marginal generators) [5,6]. The difference between average MEFs and their corresponding AEFs vary from 2 - 35% over regions in the US [5]. MEFs are more appropriate than AEFs for estimating emissions implications of short term demand changes, such the implementation of an energy efficient lighting systems [5,7] or battery electricity vehicle charging [7,8] and have been shown to affect CO_2 emissions calculations as much as 50%[6,8]. Additional and avoided electricity use affects electricity systems at three different time scales: short term electricity grid balancing over seconds to an hour, short term system electricity trading from an hour to a year, and long term infrastructure planning years ahead [5,6].

MEFs reflect short term systemic effects of electricity interventions [5,6,9]. Large amounts of net migration into regions will certainty effect long-term energy planning like the building and closing of power stations, which in turn will affect AEFs over time. However, these long-term effects are not reflected in MEFs, which in our opinion make AEFs more appropriate for this analysis.

3.1 Household Characteristics, Types of Moves, and Sampling Migrating Households

3.1.1 Population Characteristics Migrators versus Non Migrators

We conducted analysis that showed characteristic differences between populations of recently migrated households versus populations longer-term resident households in DESTINATION states. Energy data for this analysis is drawn from RECS data, which is representative of the US population, both migrating and not; however the characteristics of populations of migrating households in their destination states differ from non-migrating households in ways that likely have energy use implications. Analysis of ACS data shows that state populations of migrating households (households that identify in the survey that they have moved to that state from another state in the past 3 years) have fewer people, smaller family incomes, live in homes with fewer rooms, and have smaller self reported utility bills than non-migrating households.

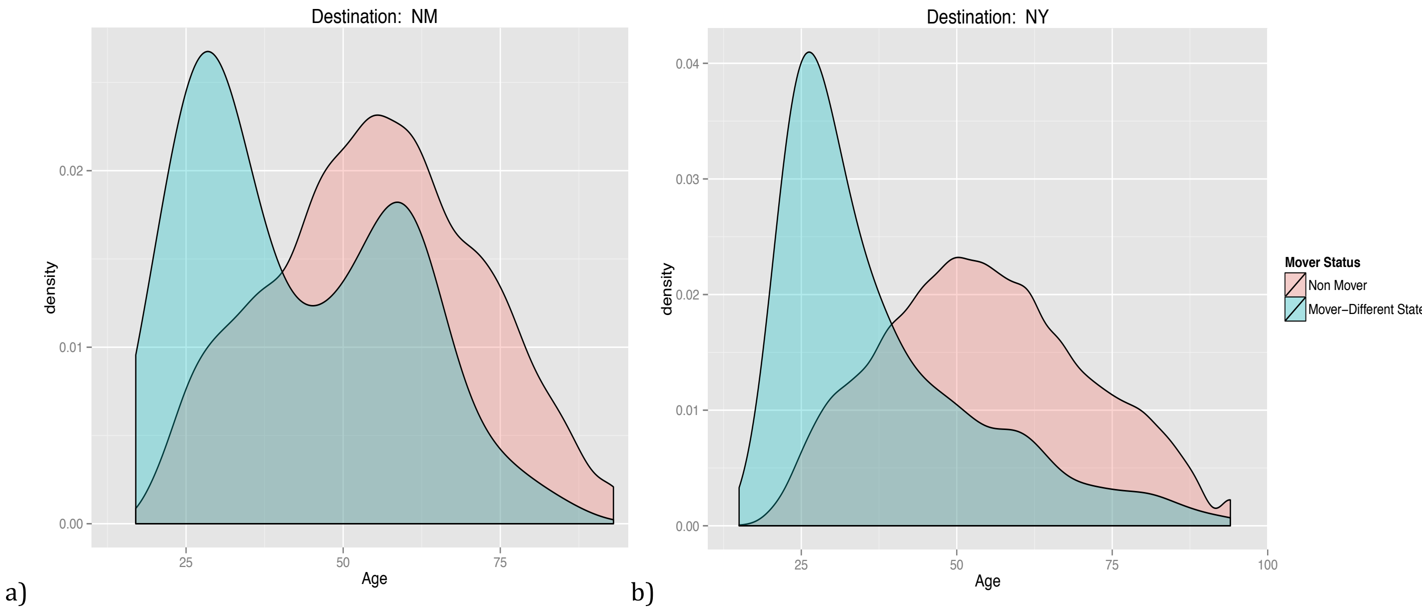


Figure 8 Distribution of the age of primary householder for migrating and non migrating populations in New Mexico (a) and New York (b)

Primary householders of migrating households are also on average 15 – 20 years younger than non-migrating households, based on the age of primary householder. However, the age distribution of migrating households in some states is bimodal, peaking at both early twenties and retirement age, while age distributions of non-migrating households are more normal, shown in Figure 8.

Individual regressions for each state were performed to predict a household's percentile of total energy use compared to other households in their states, using self-reported energy bill data. They show that accounting for age, income, and number of people in the household, migrating households use less energy than non-movers; a household can be expected to shift up to 10 percentiles lower, given that it recently moved to that new state. We concluded that a household is more likely to have smaller self reported energy use, smaller income, few rooms, and be younger if it has moved to a new state in the past year. The magnitude of differences in populations of migrating and non-migrating households vary widely across states. We were unable, however, to find data that can connect or inform if those differences also apply in ORIGIN States. We cannot conclude that household that is likely to move in the next year is also smaller, younger ect.

3.1.2 *Explanation and Discussion of Destination State Characteristic Differences*

Incorporating these destination state characteristic differences into our analysis is a part of a larger modeling task that involves 2 decisions and other considerations. First, how to select/draw/sample households from the general population and identify them as migrating households; and second, how to relate that household's origin and destination state energy uses. This is influence by 3 factors, explained below, that influence these 2 decisions in competing ways.

3.1.2.1 *General Characteristics of Migrating Households*

The section above explained some characteristic differences in populations of recent migrators and longer-term residents in destination states. However, these differences vary widely over states. Additionally, three are no data support these demographic differences for households in origin states, or connect how characteristics of a household will change over the course of a move (ie how income might change). This poses a number of pertinent questions. Do younger, smaller, lower income households move more often? Do the demographic differences we see in destination states also apply to Origin States. Do households with similar characteristics (different from a representative state or US population) more to a single state more often? ie: Do older households move to Florida or New Mexico?

On average over the US, migrating households are younger and smaller than no migrating households. Applying this shift to only the energy distribution of households in their destination states (which is the only assumption that can supported by data) without applying the same shift to households in their origin state will bias our results. It will likely make emissions savings larger and emissions increases smaller.

In many cases we believe that these characteristic differences do apply, ie: smaller, younger, lower income households move more often and will use less energy (compared to other households around them), wherever they are located. If this is the case, and we sample younger, smaller households from the US population as migrating households, then estimated emissions will be smaller in both origin and destination states, and the difference in low energy percentile household moves versus high energy percentile moves will be smaller (closer to zero). In this case, the magnitude of total emissions changes may be smaller, but the conclusions of this analysis will stay the same (emissions changes vary over regions and states but cancel to zero over the entire US). However, we know that this is likely not the case for certain origin-destination flows that see a high volume of retirement moves.

3.1.2.2 Types of Moves

Households move to different states for different reasons. The Census reports that reasons for moving vary widely over many reasons including family reasons (Marital Status change, establishing own household), job related (retirement, new job or transfer), housing related (change in owner/renter status, eviction), and other (natural disaster, climate change)[10]. Likelihood of these reasons for moving also varies widely over race, age, and gender.

We believe that specific types of moves have energy related consequences, which will influence the relationship between residential energy percentile of households in origin and destination states. This analysis assumes that the residential energy percentile of households in correlated in origin and destination state. If a household moves to a new state because of retirement, it is likely they will downsize to a smaller house and the households energy percentile will be lower than this model estimates. In this case, these households will experience more emissions savings than estimated (emissions increases will be smaller and emissions decreases will be larger). The opposite is true for households that move for reasons related to likely upsizing (new job, higher income).

There is no state specific data to infer the flow size of types of moves to different states, but we can make casual observations about flows such as New York to Florida, one of the larger migratory flows in the US, which is likely dominated by retirement moves. The average household moving to retirement destination state, like Florida or New Mexico, may experience a larger emissions savings (or smaller emissions increase).

3.1.2.3 Behavior or Migrated Households

Studies have shown that households retain similar mobility behaviors to their origin locations after recently moving[11]. This may also be the case for residential energy usage. This phenomenon, may dampen the magnitude of emissions changes estimated in this study. While the total magnitude of changes may decrease because of this phenomenon, the qualitative results of this study will likely not change. The emissions sums of regions experiencing emissions increases will remain positive and sums of regions experiencing emissions decreases will remain negative.

3.1.2.4 Model Implications

These three categories of questions/problems bias our model in inconsistent and competing ways. While general trends can be supported by studies or data, adjusting the model for these issues at the state level would be largely unsupported by state specific data. Rather, these assumptions would be made by qualitative hunches. For example moves from NY to Florida is likely dominated by retirement moves, however we have found no comprehensive data to describe types of moves, or retirement flows. We cannot make assumptions about the reasons for moves for most OD flows. If we made the assumption that households are smaller, younger, and have lower income, our model estimates would be highly biased against high retirement flows. We believe that the balanced effects of accounting for characteristic qualities of movers versus non-movers and different types of moves will likely cancel out. Beyond random effects, our model accounts for neither upsizing nor downsizing moves. We believe that any accuracy gained from adding average or uninformed modeling complexities required to account for these issues would likely be clouded by the additional bias/uncertainty associated with those assumptions.

3.2 Sensitivity: Relating Residential Energy Use in Origin and Destination States

3.2.1 *Income and Total Energy (BTU) method*

Table 8 Comparison of Results for BTU and Income method

	Income	Btu		Income	Btu		Income	Btu
AL	33,700	64,900	**KY**	96,600	36,500	**ND**	28,200	19,700
AK	17,900	22,700	**LA**	5,710	32,700	**OH**	148,000	160,000
AZ	60,400	212,000	**ME**	4,680	7,330	**OK**	67,600	34,100
AR	4,070	16,300	**MD**	68,700	84,700	**OR**	-139,000	-188,000
CA	-1,060,000	-1,550,000	**MA**	2,350	-39,000	**PA**	-34,600	-126,000
CO	83,400	21,100	**MI**	81,900	104,000	**RI**	8,210	10,800
CT	20,500	27,900	**MN**	71,100	113,000	**SC**	-108,000	-23,000
DE	29,300	18,600	**MS**	19,500	30,300	**SD**	-1,070	25,300
DC	22,800	23,800	**MO**	187,000	205,000	**TN**	37,300	91,700
FL	-222,000	-347,000	**MT**	47,000	51,400	**TX**	234,000	203,000
GA	178,000	172,000	**NE**	10,400	29,600	**UT**	130,000	113,000
HI	65,300	57,100	**NV**	153,000	152,000	**VT**	-9,970	6,150
ID	29,500	114,000	**NH**	-1,770	14,900	**VA**	36,600	124,000
IL	137,000	321,000	**NJ**	43,600	110,000	**WA**	-307,000	-402,000
IN	117,000	76,100	**NM**	51,900	22,100	**WV**	34,700	8,150
IA	63,900	65,100	**NY**	-151,000	-185,000	**WI**	71	-15,300
KS	22,600	45,800	**NC**	-35,500	-29,200	**WY**	38,200	25,800
						US	422,000	169,000

3.2.2 Correlation of origin and destination state energy use percentiles

A major assumption of this model is the energy use of a household compared to other households in its origin state is related to the energy use of a household compared to other households in its destination state. Energy use of a migration household was modeled by generating a pair correlated uniform variables between 0 and 1 to represent a household's percentile of energy use in its origin and destination state. Conversion of randomly generated correlated normal variables to uniform variables then finally the total energy use of a household based on RECS data is not a linear process, so the correlation of paired household energy use is much smaller than the correlation of the original randomly generated pair of normal variables, shown in Table 9.

Table 9 Correlation or Randomly Generated Variables and Energy use

Correlation of randomly generated normal variable	1	0.95	.5	0
Correlation of total energy use	0.88	.83	0.0012	0

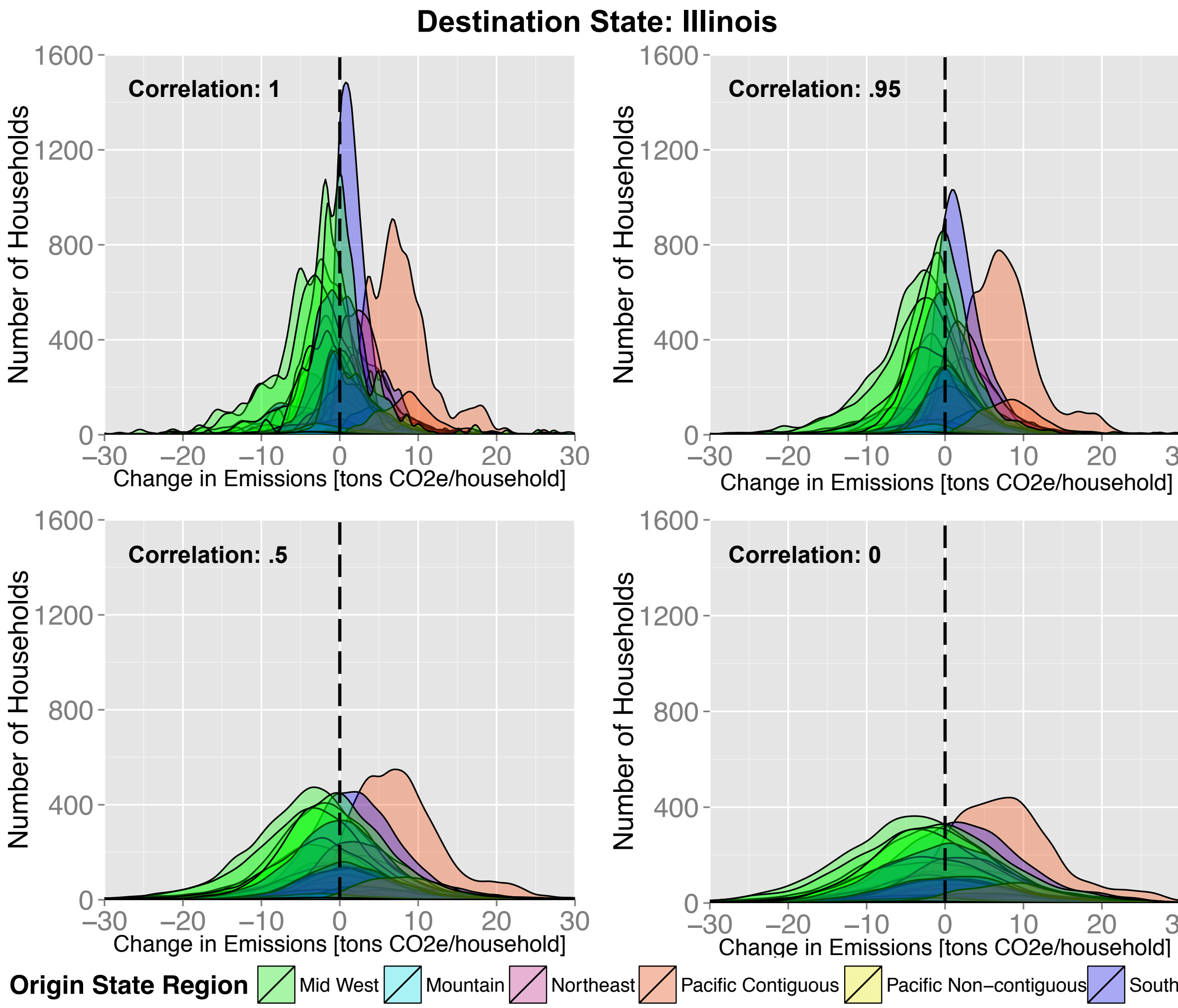


Figure 9 Distributions of expected household emission changes for households moving to Illinois by origin state using different correlation values to describe the relationship between a household's origin and destination state energy use percentile. The figures show correlation of generated random normal variables before transforming them to random uniform variables, which estimate percentile of energy use. The resulting correlation of a household's energy use in origin and destination state is shown in Table 9.

This paper shows results using a correlation of 0.95 for randomly generated normal variables, which results in a correlation of 0.83 for total energy use of household in origin and destination states. Figure 9 shows the distributions of household emission changes for households moving to Illinois by origin state using different correlation coefficients. US aggregate and state emission sums remain similar when using different correlation coefficients.

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