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ABSTRACT

As the public and policy makers continue to become more concerned with climate change, researchers continue to seek to understand and explain energy and greenhouse gas (GHG) emissions trends and their drivers. Living and existing in different areas is associated with different impacts, so growth in different areas, as well as the movement of people to and from those areas will affect energy use and emissions over US, individual states, and counties.

First the emissions implications of state-to-state mobility on household energy and GHG emissions are explored. 3 million households move across state lines annually, and generally move from the North East to the South and West. Migrating households often move to states with different climates, and thus heating and cooling and needs, different fuel mixes, and different regional electricity grids which leads them to experience changes in household emissions as a result of their move. Under current migration trends, the emissions increases of households moving from the Northeast to the South and Southwest are balanced by the emissions decreases of households moving to California and the Pacific Northwest. The net sum of emissions changes for migrating households is slightly positive but near zero; however, that net zero sum represents the balance of many emission changes. Summing emissions changes over individual states and regions show the regional differences in household emissions.

Next, a similar analysis is conducted for the 120,000 households that annually move between counties in Pennsylvania. From 2006 – 2010, the emissions changes experienced by those households balanced to near zero values, similar to the state analysis. The emissions increases from households moving to metropolitan fringe and suburban counties

were countered by the emissions decreases from households moving to low emission urban centers, even though urban centers experienced net negative migration. While emission changes experienced by households were dominated by differences in emissions from residential energy use, emission changes for household moving within Pennsylvania were dominated by differences from transportation emissions.

Finally, this thesis explores the long-term effects of growth and decline at the metropolitan level by estimating fossil-based CO_2 emissions from 1900–2000 for Allegheny County, Pennsylvania. From 1970 to 2000, Allegheny County experienced a 30% decrease in total emissions and energy use from peak values, primarily because of a decline in industrial activity (40% decrease in value added) and the loss of a quarter of its population. Allegheny County's history suggests that the scale of change needed to achieve local emissions reductions may be significant; given years of major technological, economic, and demographic changes, per capita emissions in 1940 were nearly the same in 2000. Most local governments are planning emissions reductions rates that exceed 1% per year, which deviate significantly from historical trends. These results suggest additional resources and improved planning paradigms are likely necessary to achieve significant emissions reductions, especially for areas where emissions are still increasing.

This work shows that overtime, growth and decline within a region drives its evolving GHG footprint. Population decline within a region may lead to emission reductions, as seen in the Allegheny County, but those reductions are more accurately described as displaced emissions due to population redistribution. From 2005 - 2010, the mobility of the US population between states, regions and counties was responsible for many household emissions changes that balce annually over the entire US. The near zero sum represents the precarious emissions balance of two kinds of household moves. First, moves resulting in moderate emissions increases either as a result of households moving to higher carbon regions, like the South or South West, or as a result of households moving higher carbon suburban counties within states. Second, moves resulting in significant emissions decreases as a result of households moving to low carbon regions or low carbon urban centers. Planning for continued low carbon growth in low carbon regions or cities experiencing high growth rates driven by migration, like California or Philadelphia, is essential in order to offset the moderate emissions increases experienced by households moving to high carbon regions or suburban areas.

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1. BACKGROUND AND MOTIVATION

As the public and policy makers continue to become more concerned with climate change, researchers continue to seek to understand and explain energy and greenhouse gas (GHGs) emissions trends and their drivers. To do this, researchers have conducted many emissions inventories and energy accounting studies, which span a broad range of geographic resolutions, time scales, scopes, and detail. Such studies, often conducted by government agencies and research boards, report broad national trends over 20 to 50 years and may report end use energy or emissions by end use energy sector; however, these often do not include high-resolution detail. The vast majorities of energy and emissions studies include short-term trends beginning in the 90's. During this time, data became more widely available and concerns about climate change became more prominent with global efforts like the Kyoto Protocol and the first and second IPCC reports on climate change. However, some fuel based national emission studies attempt to estimate energy use or emissions back to the mid 19th century (Tol, Pacala, and Socolow 2009; Lindmark 2002).

Some emissions studies estimate footprints across multiple cities or geographies, using the same method, and are meant to compare and bench mark different geographies (Sovacool and Brown 2010; Brown, Southworth, and Sarzynski 2009). Others are specific to a single city or county, in higher detail, and are intended to begin or track the progress of achieving emissions mitigation goals. These studies include different scopes of emissions in their inventories. Long term emissions inventories often only report scope 1 emissions (direct emissions from burning fuel and process emissions) and scope 2 emissions (indirect emissions from electricity and steam, aka, IEAP) (WBCSDWRI 2004). However, some detailed inventories, often those conducted by individual cities, include scope 3 (other indirect emissions) and life cycle emissions (Ramaswami et al. 2008).

Researchers have developed different paradigms to explain the trends in these footprints. Many of these techniques involve relating energy and emissions changes to economics, social, technological trends, such as the IPAT equation and it's derivatives, which relates environmental impact to population, affluence, and technology change (Chertow 2000; York, Rosa, and Dietz 2003).

While the US has experienced increases in population and GDP overtime with related and similar increases in energy and carbon emissions, some regions within the US have experience more dramatic economic, industrial, and population trends that are muted when examined as part of US national averages. These regions may have also experienced different energy and carbon trends than the US. The Pittsburgh Region is such an example. After growing as the steel production powerhouse of the United States through the mid 1900's**,** Allegheny County experienced a significant decline of heavy industry, jobs, and population throughout the 1970s and 1980s when the steel industry fell. Significant and unique socio-economic changes over the century likely influenced its energy use and GHG emissions to the extent that Allegheny County drastically different energy and emissions trends than the US over similar time periods.

While Allegheny County's decline in economic productivity and transition from energy intensive industry to lower energy commercial industry likely contributed emission trends, its massive decline in population is of equal interest. Population has long been known to be a primary driver of environmental impacts(York, Rosa, and Dietz 2003; Wei 2011; Dietz and Rosa 1997; Chertow 2000); population and population projections remain vital for energy and emissions planning. Overtime, even in the wake technology changes, the growth and decline of population in cities contributes to significant changes in its energy and emission scene. However, when areas experience emissions decreases due to large population loss, like Allegheny County, these emissions reductions are more accurately described as displaced emissions. The exiting population goes on to use energy and produce CO_2 emissions elsewhere. Moreover, since both regions in the US and counties within states differ by climate, fuel mix, housing stock, urbanity, or other characteristics, the energy use and emissions of people that relocate within the US and within states may change and contribute to net changes in energy use and emissions.

Overtime, the concentration of US population has continually shifted south and west and continues to follow the trend. Between 2000 and 2010, regional growth in the South and West (14.3 % and 13.8% respectively) was faster than in the Midwest and Northeast (3.9% and 3.2% respectively) (US Census Bureau 2011). The movement of population to different regions, with different residential energy needs, fuel mixes, and electricity mixes likely contributes to the changing landscape of household energy use in the US. The migration growth trends of urban and rural counties, however is not consistent. From 2006 - 2010 central metropolitan counties in the US experienced less population growth than outlying counties; however, over 2010 - 2013 core counties experienced a higher growth rate than outlying counties. The largest contributor to population gains in 45 of the 50 largest metropolitan areas was net migration, rather than natural growth(Toppo and Overberg 2014).

This thesis explores the idea that living and existing in different areas is associated with different impacts, so growth in different areas, as well as the movement of people to and from those areas will affect energy use and emissions within the US, states, and counties. The main chapters in the thesis each include their own background and literature review. In chapter 2, I will begin by exploring the implications of inter-state migration in the US on household energy and emissions by highlighting the population shift south and west to regions with varying climate and fuel mix. In chapter 3, I will then examine similar effects on county-county migration in Pennsylvania, highlighting the urban-rural index of counties. In chapter 4, I will look at the long-term energy and emissions effects of regional growth and decline by estimating the carbon footprint of the Pittsburgh region over 100 years. Chapter 5 will draw conclusions and policy implications from this analysis.

2. ENERGY AND EMISSIONS FROM US POPULATION SHIFTS AND IMPLICATIONS FOR REGIONAL GHG MITIGATION PLANNING

2.1. Background

Due to the absence of comprehensive national climate planning in the last decade, there has been a large increase in local and regional sustainability and greenhouse gas (GHG) mitigation planning. Many cities and counties have done so by creating Climate Action Plans (CAPs), which include conducting GHG emissions inventories, establishing reduction targets, developing and implementing strategies to meet those targets, and monitoring results by conducting additional GHG inventories. To date, 32 states have completed climate action plans and more than 1,000 cities have committed to local emission reduction initiatives by becoming members of ICLEI Local Governments for Sustainability (ICLEI USA 2013; US Environmental Protection Agency 2013). These cities face many challenges (Blackhurst et al. 2011; Dhakal and Shrestha 2010),but it seems especially difficult for cities to achieve overall emission reduction goals alongside increasing populations and energy demand (ICLEI USA 2013; Hoesly et al. 2012; US Environmental Protection Agency 2013). The redistribution of population throughout the US contributes to changes in energy and emissions within specific regional or local boundaries; these emission changes are partially documented in local GHG inventories as some portion of net emission increases or decreases due to population gains and losses. Moreover, since regions differ by climate, fuel mix, housing stock, and other characteristics, the energy use and emissions of people that relocate within the US may change and contribute to net changes in energy use and emissions at the national level.

Studies have shown that household energy use and GHG emissions vary widely across the US for many reasons (Blackhurst et al. 2011; Glaeser and Kahn 2010; Dhakal and Shrestha 2010; Hillman and Ramaswami 2010; Min, Hausfather, and Lin 2010). Residential energy use and household transportation both vary differently over states. Average annual vehicle miles traveled (VMT) per capita varies by state from less than 9,000 VMT/person in Pacific Northwest states, to over 11,000 VMT/person in states characterized by open spaces like Colorado, Mississippi, and Wyoming (Puentes and Tomer 2008).

Residential energy, which accounts for 21% of total primary energy consumption and 17% of total GHG emissions in the US (US Energy Information Administration 2008; US Energy Information Administration 2011a), is influenced by many factors including lifestyle choices, household income, and use of energy efficient appliances and lighting (Lima Azevedo et al. 2013). Most notably, residential energy use is dominated by heating and cooling, which accounts for 48% of energy use in homes (US Energy Information Administration 2013b), and is highly correlated with heating degree days (HDD) and cooling degree days(CDD), a measurement of the difference between mean outdoor temperature and room temperature(Quayle and Diaz 1980). Average household energy use is highest in the Midwest and Northeast (as defined by the US Census), 112 and 108 MBTU/year respectively, followed by the South and West (76 and 73 MBTU/year respectively)(US Energy Information Administration 2012b).

Variations in residential GHG emissions arise from differences in total energy demand combined with regional variation in fuel mix and carbon intensity of the regional electricity grid. In Florida, almost 30% of household energy is used for space cooling, resulting in large electricity consumption (90% of all energy consumed by Florida homes)(US Energy Information Administration 2013c). While in Colorado, electricity use is low because it is not commonly used for space heating, cooling, or water heating, even though total household energy use is higher than the US average (US Energy Information Administration 2013d). The electricity grid mix varies across the US by state and region, shown in Appendix A. Despite the difficulty associated with estimating local grid factors, state average electricity emission factors in different regions varies from less than 0.3 kg CO_2/kWh the Pacific Northwest, where states employ large amounts of hydro power, to 0.8 kg CO_2/kWh in states that rely heavily on coal (Weber et al. 2010).

In 1960, just over 30% of the country lived in the warmest states (less than 4000 annual average HDD), but by 2010 that share had grown to 43%; while the percentage of population living in coldest states decreased from 60% to 48% (US Energy Information Administration 2012a). This has led to a decrease in HDD and an increase in CDD, which while driving the growth of air conditioning and electricity use in the South, has contributed to the flattening of per capita energy use in the US overtime (US Energy Information Administration 2012a; US Energy Information Administration 2013b; Michael Sivak 2009; Samson et al. 2012).

The American population continues to be mobile, and while the numbers of migrating Americans have decreased since 2000, 35 – 40 million people change address in the US every year (Ihrke, Faber, and Koerber 2011). In 2005, of these moves, 57% of households stayed within their original county of residence, 20% moved to a different county in the same state, and 19% move across state lines, with 4% moving to or from outside the US (US Census Bureau 2005). Figure 2-1, using data from the International Revenue Service (Internal Revenue Service Statistics of Income Division), shows the annual average net migration from 2005 – 2010 into states in number of households. Annual state-to-state migration patterns have been relatively consistent since 2004 (with the exception of the Gulf Coast area). Households continue, on average to move from the Northeast to the South and West.

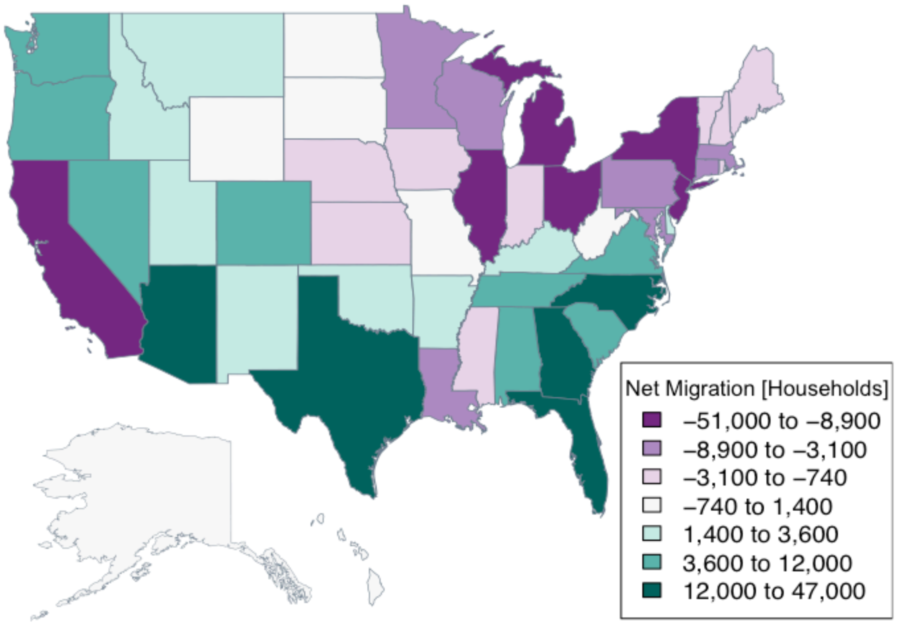


Figure 2-1 Net migration into states. Average of annual migration flows from 2004 – 2010, estimated by the IRS Area to Area Migration Data.

While previous studies have shown that the long-term population shift has had effects on US residential energy use, the population shift should also influence residential GHG emissions. This analysis explores how inter-state migration contributes to net changes in GHG emissions within the US by estimating the energy use and GHG emissions of migrating households in their origin and destination states and calculating the annual change in household GHG emissions as a result of moving to a different state. While this analysis primarily focuses on residential energy use, it also examines the effect of household transportation on the changes in total household emissions of migrating households.

2.2. Data

The major data required to conduct this analysis were residential energy data, migration and demographic data, electricity grid emission data, and household transportation data.

2.2.1. Migration and Demographic Data

6 years of mobility data, over the period 2005 – 2010, from the US Internal Revenue Service (IRS) area-to-area migration data sets are used (Internal Revenue Service Statistics of Income Division). The IRS Statistics of Income (SOI) Division reports migration based on the change of address fields in annual tax returns. Both annual state-to-state and county-to-county datasets provide yearly estimates of the number of households and persons moving, origin and destination locations, and aggregate and median income for each migratory flow. IRS migration data is often used, rather than the other 2 primary migration data sets from the US Census and American Community Survey (ACS) and the Annual Social and Economic Supplement of the Current Population Survey (CPS). IRS migration data excludes those who do not file taxes and may underrepresent the poor and the elderly as well as those granted extensions to file by the IRS, like those with very high income (Gross 2012). Although CPS data shows that the population of tax filers may migrate more frequently than non filers, this does not affect reporting of migration trends and IRS data remains the most comprehensive data set for the US, reporting paired flows for both state and county (Molloy, Smith, and Wozniak 2011). In order to protect the privacy of taxpayers, the IRS suppresses data on flows with small numbers of households; state flows with at least 3 households and county flows with at least 10 households are published. While origin and destination state data for all households migrating within the US are provided, the origin and destination county within those states is only disclosed for roughly 60% of those households. That 60% includes households that migrate within the same state and those that migrate across state lines. Even though a majority of moves in the US every year are within the same state or same county, this chapter is limited to a state-level analysis. Cross-county, in-state moves are addressed in Chapter 3 of this thesis.

Additional household information is drawn from the 2009 1-year sample ACS (US Census Bureau). The ACS, conducted by the US Census Bureau provides annual household (and individuals within those households) demographic data, including recent migratory status, renter or owner status, as well as limited self-reported utility bill data.

2.2.2. Residential Energy Data

Residential energy use data is available from the US Energy Information Administration's (EIA's) 2009 Residential Energy Consumption Survey (RECS) (US Energy Information Administration 2013a). RECS contains data on household energy use sampled from over 12,000 households in 16 states, representing 27 domains (groups of states) and is considered the most comprehensive household energy survey for US homes. While RECS summary tables include summary statistics of household energy use and expenditures of US households by domains and characteristics, RECS microdata contains survey data from all individual households sampled along with representative weights used to estimate representative population distributions. RECS data used in this analysis includes annual residential energy use by fuel type including electricity, natural gas, fuel oil, liquefied petroleum, kerosene and fuel oil.

2.2.3. Household Transportation Data

The changes in household transportation emissions for migrating households are calculated using state average estimates for VMT per household. State estimates were derived from total annual VMT estimates per state, available from the Federal Highway Administration's (FHWA) Highway Statistics Series (Federal Highway Administration 2011), and census estimates of the total number of households per state. VMT estimates were calculated for 2005 and 2010, shown in Equation 1.

$$\frac{\boldsymbol{Average\,VMT}}{\boldsymbol{Household}}_{\boldsymbol{i}} = \boldsymbol{Total\,VMT_i} \div \boldsymbol{Number\ of\ Households_i}$$

Equation 1

Where:

$\frac{Average\ VMT}{Household}_i$ is the average annual VMT/household in state *i;*

$Annual\ VMT_i$ is the total VMT in state *i* for all vehicles;

$Number\ of\ Households_i$ is the total number of households in state *i*.

Total annual vehicle-miles, reported by the FHWA, is the compilation of data that are both collected from individual states and calculated by the FHWA using state-provided data in the Highway Performance Monitoring System (HPMS). Rather than actual odometer readings from vehicles, these values are usually based on annual average daily traffic (AADT) and centerline length for reported AADT sections. In some cases, vehicle miles are based on fuel use or supplemental traffic counts (Federal Highway Administration 2010).

Similar to household energy use data, microdata exists describing household transportation behaviors over different states from the DOT's National Household Transportation Survey (Federal Highway Administration 2009a). A discussion of why such microdata is not used in this analysis is in the Methods section.

2.3. Methods

Historical migration data and energy use survey data were used to individually estimate the residential energy use and GHG emissions of all migrating households over a given year in their origin and destination states. In this analysis, the expected change in annual emissions for a migrating household is the difference between annual emissions from residential energy use from living in the previous (origin) and new (destination) state.

From the IRS migration data, 6 51x51 origin-destination (OD) matrices were created, containing the number of households that moved from each state (and the District of Columbia) to every other state over each year from 2005 - 2010. This analysis uses the average annual flow, or the average of each cell over the 6 OD matrices. The 2,550 non-zero flows range from less than 20 households for small flows (Idaho to Delaware), to over 30,000 households (New York to Florida).

2.3.1. Residential Energy and Emissions

The energy use of migrating households in their origin and destination state was estimated using a process of resampling energy use data for single households from the 2009 RECS microdata. The RECS microdata was split into 27 groups, by RECS domain, with many domains representing multiple states, as defined by RECS. For some states, the energy use of individual households is estimated by sampling from the same distribution, because there are 51 states (and DC) but only 27 domains. Using representative household weights provided by RECS, 27 empirical distributions were established from which to sample household energy use data. The RECS data is designed to be representative of the American population; the assumption of whether it is also representative of the migrating population is discussed in the Limitations section below. Only 1 year of energy data, the 2009 RECS microdata, is used for all 6 years of mobility data. RECS samples are also available for 2005; however, this survey samples less than half the number of households from fewer states than the 2009 sample.

Two methods were considered for estimating the relationship between residential energy use of a single household in its origin and destination states: first by percentile of total energy use, then by household income. Both methods yielded similar results, shown in Appendix A. Results shown in the body of this report reflect estimation by total energy use.

For a single household, a pair of correlated random uniform numbers between 0 and 1 were created to represent a household's percentile of total energy use in both origin and destination state, measured in total BTUs per year. We assumed these values are highly correlated because in most cases, it is likely that a migrating household's energy habits, such as willingness to use energy to provide comfort (like space heating or air conditioning) relatively compared to other households in the same state would be fixed. In other words, it is unlikely that a household would jump from having energy use at the 95th percentile in its origin state, to 5th percentile in its destination state. Percentile pairs were generated so that they would have a correlation of about 0.8; sensitivity of this assumption is discussed further in the Limitations section and the Appendix A. Correlated uniform numbers were created by randomly generating correlated random normal variables then transforming them to uniform variables using cumulative Gaussian distribution functions.

Using the correlated uniform variables that represent percentiles of total energy use, 2 observations are drawn from the RECS microdata, to approximate energy use behavior of the household in both the origin and destination state. Each household sampling draws complete data for a household entry in RECS including annual consumption of electricity, natural gas, kerosene, fuel oil, and liquefied petroleum gases.

When using income to estimate the energy use of households in origin and destination states, a household was randomly sampled from origin state distribution then matched with a household in the destination state data with similar income. Complete data for each household was then sampled and retained for analysis.

Next, GHG emissions, measured in CO_2eq, for the household in the origin and destination state were calculated using life cycle GHG emission factors for natural gas(Venkatesh et al. 2011; Advanced

Resource International Inc and IFC International 2008), fuel oil, liquefied petroleum gas (propane) and kerosene, detailed in Appendix A.

Emissions from electricity were calculated using the state emission factors and regional emission factors reported by EIA (US Energy Information Administration 2002b), which are comparable to eGRID emissions factors reported by the US Environmental Protection Agency (EPA)(US EPA 2014). Emission factors are measured in CO_2eq and detailed in Appendix A. A discussion of sensitivity from electricity emission factors is discussed in the Limitations section.

The estimated emissions, Em_i^n, of migrating household, *n*, in origin state, *i*, is

$$Em_i^n = E_{i,e}^n \times EC_i + \sum_k E_{i,k}^n \times C_k$$

Equation 2

Where:

$E_{i,e}^n$ is household n's annual electricity use in origin state, *i*, measured kWh;

EC_i is the electricity grid emission factor in origin state, *i*, in lbs/kwh;

$E_{i,k}^n$ is household n's annual energy use in origin state, *i*, of fuel *k*, which includes natural gas, fuel oil, liquid petroleum, and kerosene; and

C_k is the carbon emission factor for fuel, *k*.

Similarly, the estimated emissions of migration household, *n*, in destination state, *j*, is

$$Em_j^n = E_{j,e}^n \times EC_j + \sum_k E_{i,k}^n \times C_k$$

Equation 3

The estimated change in emissions, for household n, Em_{Delta}^n

$$Em_{Delta}^n = Em_j^n - Em_i^n$$

Equation 4

This process is repeated roughly 3 million times for each of the households that move between states in a given year using origin and destination states according to the Origin-Destination matrix mentioned above. The energy use and emissions for each household in its origin and destination states as well as the expected emissions change the household experiences from the move is retained for later analysis. A flow diagram illustrating this methodology is shown in Figure 2-2.

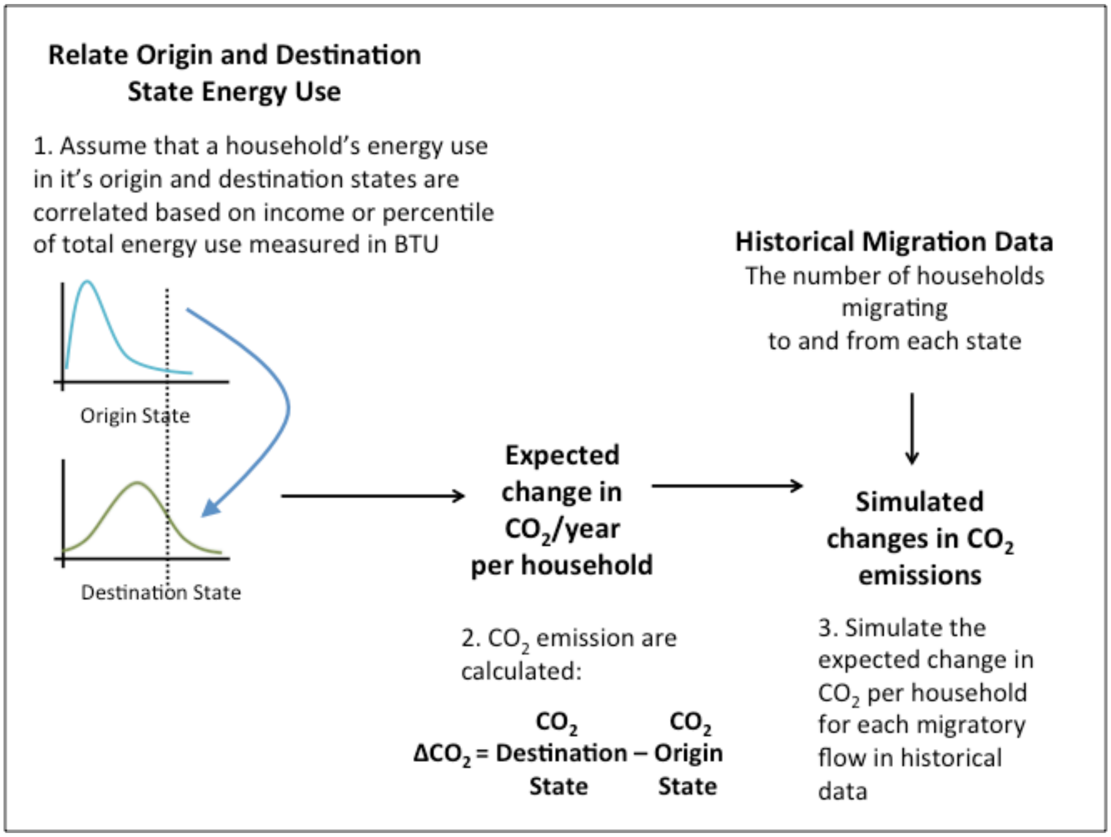


Figure 2-2 Flow diagram illustrating method for estimating the changes in residential energy emissions for migrating households.

2.3.2. Household Transportation Energy and Emissions

Described above, changes in residential energy emissions were simulated for individual households and are shown, in the next section, as distributions. However, the household transportation emissions for migrating households were estimated using average point estimates to approximate distributions of actual household transportation emissions changes experienced by households. Many households will experience emissions changes different than the average estimates; aside from regular variation in samples, these differences are likely driven by factors that vary within states, such as urbanity. Analysis in this chapter, does not model sub state variation; however, this is addressed in Chapter 3. We believe that, unlike residential energy use, there is no clear correlation between the driving habits of a household in its origin and destination state. Annual

VMT is dominated by trips to work; estimating a migrating household's proximity to work place, as well as attempting to estimate a relationship between household driving behavior in origin and destination states beyond state averages, are outside the scope of this thesis. Therefore, the use of microdata distributions is unnecessary and point estimates will sufficiently describe the difference in driving behavior and resulting emissions changes between states in the US.

Average fuel use per household for each state was calculated using total Annual VMT estimates per state, which are available for the years 2005 and 2010 from the US DOT (Federal Highway Administration 2011; Federal Highway Administration 2005), census estimates for the number of households per state, and the average fuel economy of the US passenger vehicle fleet measured in mpg (22.1 and 23.3 mpg for 2005 and 2010 respectively) (US DOT Bureau of Transportation Statistics) according to Equation 5. As fuel economy varies with levels of urbanity (Transportation Research Board), the average fuel economy of vehicle fleets also likely vary by state; this data however, is not readily available. Average vehicle fuel economy can be derived from NHTS microdata; however, the sample size for many states is quite small, less than 300 vehicles, compared to a select few states which have more than 15,000 samples like California, Florida, and New York (Federal Highway Administration 2009a). The statistical difference in fuel economy between many states will likely be indistinguishable from zero.

$$F_i = \frac{Total\ Annual\ VMT_i}{Total\ Households_i} \div US\ fuel\ economy$$

Equation 5

Where:

F_i is the average fuel use per household in state *i.*

A 51x51 fuel-change matrix was created which describes the change in annual fuel use of an average household moving from one state another described in Equation 6:

$$\Delta F_{ij} = F_j - F_i$$

Equation 6

Where:

ΔF_{ij} is the average change in fuel use for a household moving from state *i* to state *j*. ΔF_{ij} is located in row *i* and column *j* of the fuel change matrix.

The fuel-change matrix was multiplied by the OD migration matrix in order to obtain estimates of total change in fuel use for all households in each migration flow. GHG emissions are estimated from fuel estimates using a gasoline emission factors, 19.32 lbs CO_2/gal (US Energy Information Administration) plus 20% to account for up stream lifecycle emissions (Glaeser and Kahn 2010).

2.4. Results

The results shown in this chapter reflect annual emissions changes from migrating households for the average annual migratory flow from 2005-2010. Total emissions changes for migratory flows for individual years do not vary widely and there is no increasing or decreasing trend. The variability from using different years of migration flow data is much smaller than uncertainty associated with electricity emission factors (discussed further in the Limitations and Uncertainty section).

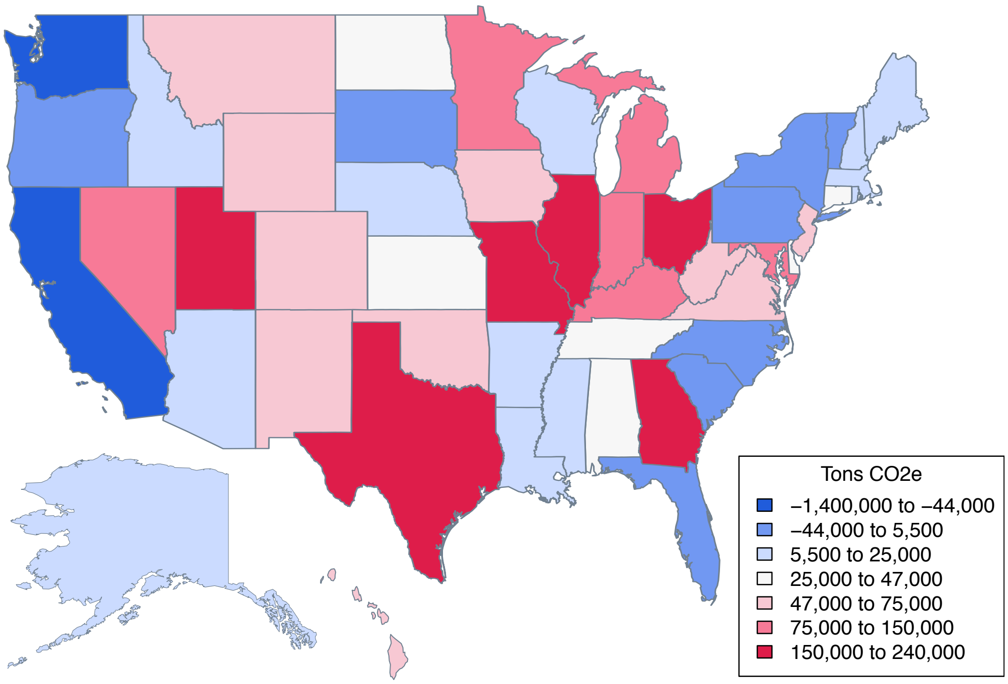
2.4.1. Residential Energy and Emissions

The aggregate estimated residential emissions changes from households migrating state to state was very small but slightly positive, ranging from 30,000 – 200,000 tons CO_2eq. Compared to annual energy related CO_2 emissions estimates from the residential sector, approximately 1.2 billion tons CO_2(US Census Bureau 2014; US Energy Information Administration 2011b), this represents less than 0.1%, and an even lower percentage on the basis of total US GHG emissions. However this near-zero value is the summation of many households experiencing increases and many households experiencing decreases in emissions from living in different states. 1.54 million of migrating households, just over half, experience emissions increases equal to 6.6 million tons CO_2eq. The remaining 1.51 million migrating households experience decreases equal to -6.4 million tons CO_2eq.

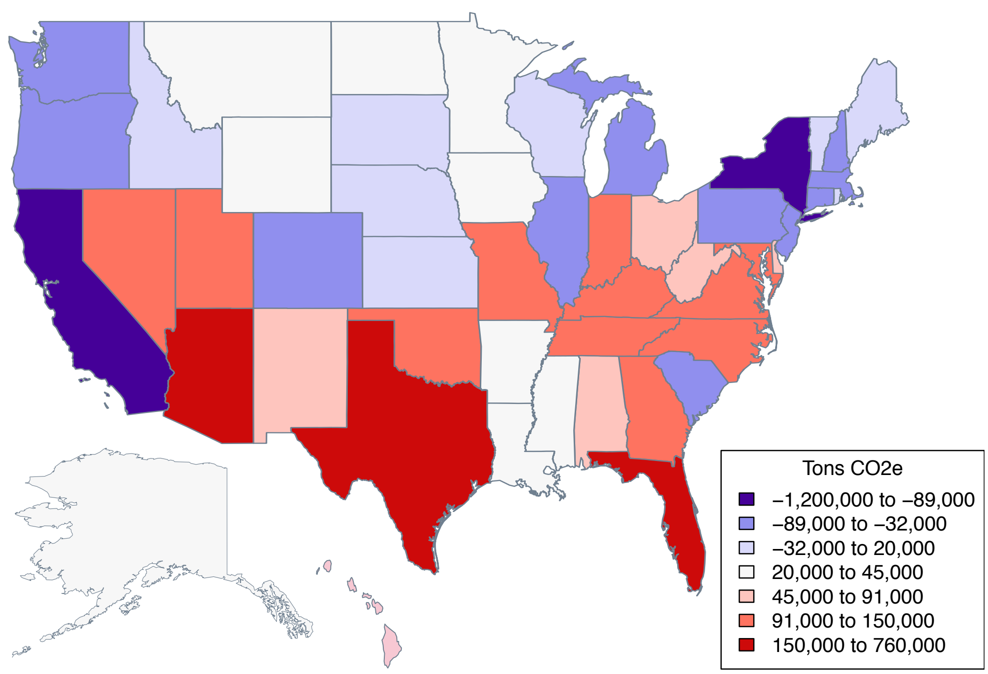
115 million households in the US (US Census Bureau 2014) emit 1.2 billion tons of CO_2 emissions annually from residential energy use, so the average household in the US emits approximately 10.4 tons CO_2 per year. Households that experienced emissions increases, on average, increased their emissions by +4.3 tons CO_2eq per year. On average, these households will emit 40% more CO_2 emissions per year than the average US household, just from living in a different state. While many migrating households experience an emissions change close to zero, the range of emissions changes a household can expect to experience is very wide. Detailed in the methods section, this analysis simulated the expected emissions changes for individual migrating households, which resulted in distributions of expected emissions changes. The 5th and 95th percentile of all household emission changes were –9.2 tons and +9.2 tons CO_2eq/hh/year respectively. In other words, in extreme cases, a migrating household may experience an emissions change that is almost equivalent to the emissions change of adding or taking away an additional average US household.

Aggregate US emissions changes from households moving in the US annually net close to zero; however, aggregate emission changes over regions and states are not trivial. Figure 2-3a shows the sum of expected total emission changes from all households moving to each state. While the figure reflects emission changes of large migratory flows into each state, it does not reflect migration out of states nor the changes in emissions within a state over a given year. Negative sums, shown in blue, indicate that on average households move to that state from areas where they were likely to emit more GHGs. Some households moving to these blue colored states, will likely experience emissions increases, but the sum of emissions changes from all household moving to those states is negative, and represents a net emissions decrease. Positive state emissions sums, shown in red, indicate that on average households move to that state from areas where they are likely to emit less GHGs. Migration to these states, based on migration flows from 2005-2010, represent a net emissions increase. Migratory flows to California, the Pacific Northwest, and the North East are responsible for net emissions decreases while flows to Texas, Georgia, and most of the Mid West and Mountain regions are responsible for net emissions increases.

State emission sums for incoming households vary from -1.4 million tons to 250,000 tons. This illustrates that the net zero emission sum for the US is the addition of many household emission increases and many household emissions decreases. California is almost solely responsible for net zero emissions balance. The 1.4 M tons net emission decreases for the almost 80,000 households moving to California every year is larger than the sum of emissions changes of all other states with net negative emission sums. California's emission sum is almost 4 times larger than the absolute value of the next largest sum, Texas, which equals almost 240,000 tons. The moderate emissions sums of households moving to red colored states are buoyed and balanced by many households moving to California and Washington; thereby decreasing their emissions significantly. A table showing the emissions change sums for all states is included in Appendix A.



a)



b)

Figure 2-3 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

Figure 2-3b which shows the sum of only electricity emission changes from all households moving to each state, looks very similar to a map reflecting the carbon intensity of electricity grids, shown in the Appendix A. This shows that household emission changes are primarily driven by state electricity grid mix, but are also influenced by variation in fuel mix and residential energy profiles. States with the largest magnitude emission sums tend to be states with either extremely low or high intensity carbon grids, like the Washington, California and Kentucky, or states with the largest migration flows like California and Texas.

Table 2-1 shows the sum of residential emissions changes and the size of the migration flow for the 6 largest emissions sums (absolute value) and 6 largest household flows. Some migration flows have both large size and emission sum like California to Texas, which is the second largest migration flow and the largest net emission sum (for a specific flow). Some large migration flows do not have large emissions consequences (e.g. New York to Florida) and other small flows have larger consequences, (e.g. California to Colorado).

Table 2-1 Net residential emission changes and size of migration flow for 6 largest flows and 6 largest emission sums

Largest Flows		
Flow	**Flow Size [Households]**	**Emission Sum [tons CO_2eq]**
NY to FL	31,912	18,400
CA to TX	28,250	224,300
NY to NJ	27,856	60,300
CA to AZ	24,297	194,000
FL to GA	22,761	57,900
CA to NV	21,141	158,200

Largest Emission Sum		
Flow	**Emission Sum [tons CO_2eq]**	**Flow Size [Households]**
CA to TX	224,300	28,250
CA to AZ	194,000	24,297
TX to CA	-136,600	17,304
AZ to CA	-113,200	14,090
CA to CO	78,500	10,786
NY to CA	-75899	13,703

Figure 2-4 and Figure 2-5 show the emission changes for migration flows between US Census Regions. Figure 2-4 shows the flows that sum to net emissions increases and Figure 2-5 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 2-4, 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 2-4 shows no flows terminating in the Pacific region, because all regional flows to the Pacific region sum to net emissions decreases.

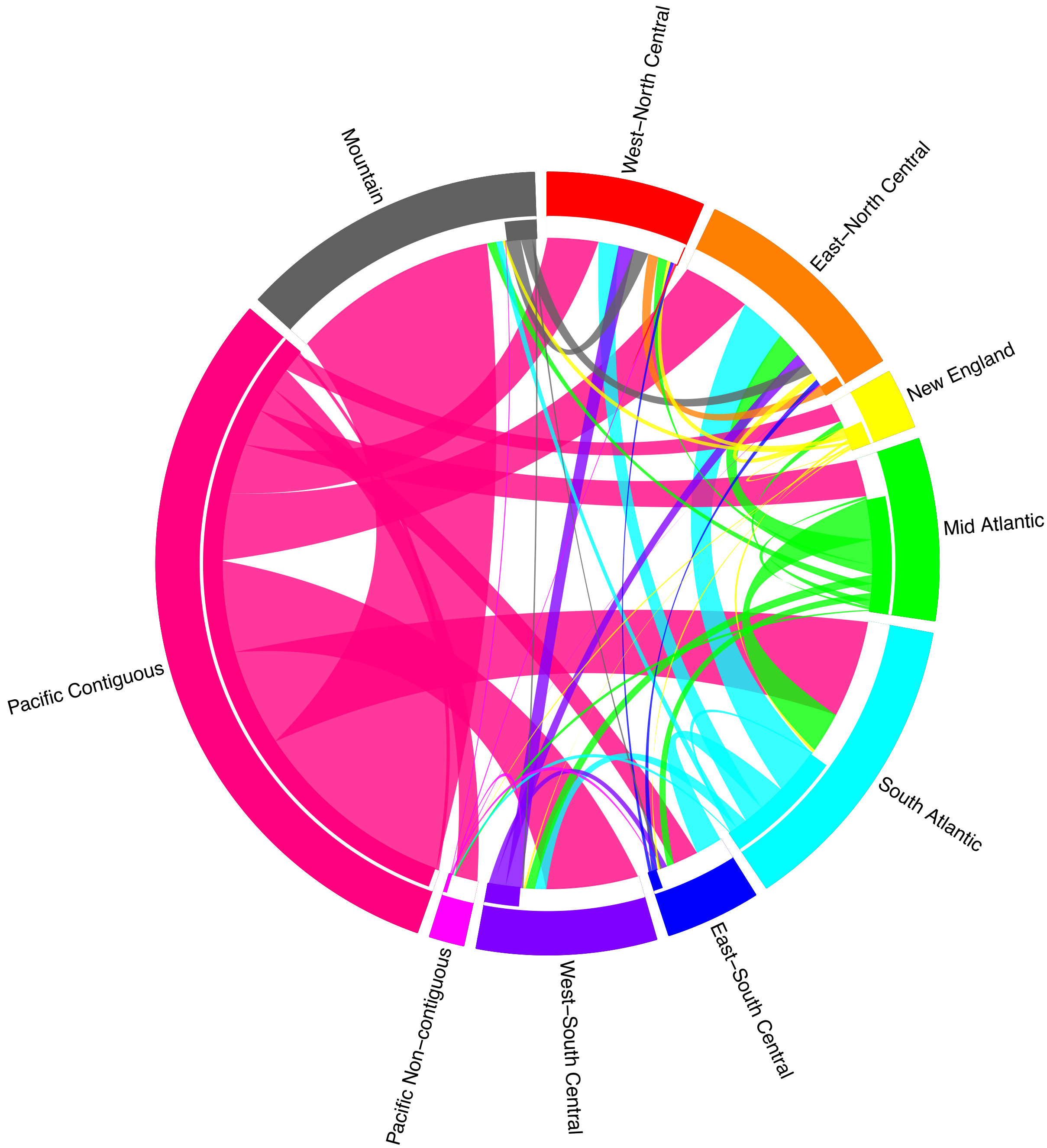


Figure 2-4 Radial migration diagram showing the sums of residential emissions changes for flows between US Census Regions that sum to net positive emissions, or emissions increases. Flows between regions representing emissions decreases are shown in Figure 2-5. The width of connecting lines represent the size of the emissions sum for all households in that flow and are colored by origin census region.

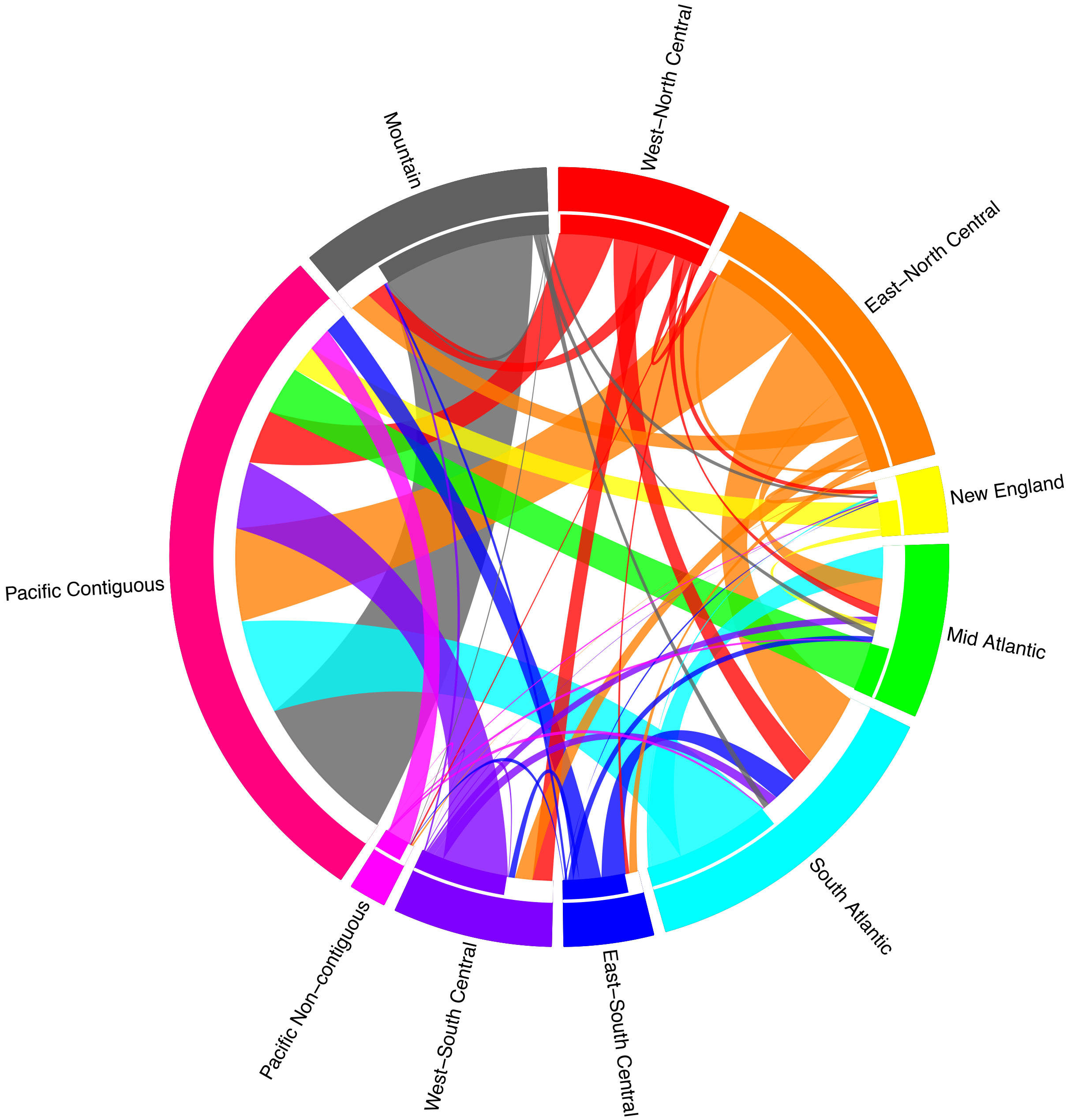


Figure 2-5 Radial migration diagram showing the sums of residential emissions changes for flows between US Census Regions that sum to net negative emissions, or emissions decreases. Flows between regions representing emissions increases are shown in Figure 2-4. The width of connecting lines represent the size of the emissions sum for all households in that flow and are colored by origin census region.

Figure 2-5, 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 2-4 and is roughly equal to the sum of emissions in Figure 2-5. Therefore, the width of the lines representing emissions flows in both figures is comparable.

Regional energy stories are further illustrated by examining the distributions of expected changes in household emissions for each migratory flow. Figure 2-6 shows the distributions of the changes in household emissions for all households moving to Colorado 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 5th and 95th 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.

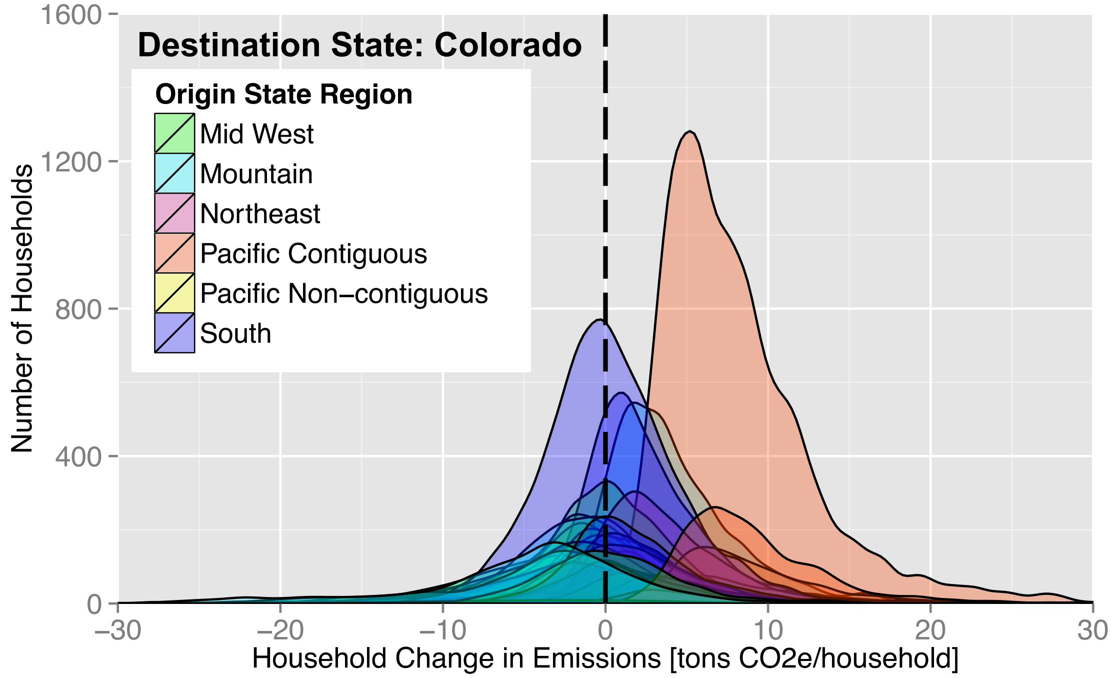


Figure 2-6 Distributions of expected change in household emissions for all households moving to Colorado. Each curve is the distribution for households moving from 49 other states and DC to Colorado, colored by origin state Census region.

When examining similar graphs for other destination states, three general stories emerge, as shown in Figure 2-7. Most states, like Arkansas, shown in Figure 2-7a are somewhat symmetrical and centered at zero. Most curves peak at and are centered around zero, meaning that most households experience an emissions change close to zero as a result of moving. In these destination states, just as many households experience an emissions increase as do an emissions decrease which result in the sum of emissions changes for households moving to such states being close to zero. States with carbon intensive electricity grids like New Mexico, shown in Figure 2-7b, have distributions that are shifted right of zero, indicating that most household moves result in an emissions increase. Lastly, some states are shifted left like Washington, shown in Figure 2-7c, where most households emit fewer emissions in their destination state than their origin state. Similar figures, for other select destination states are shown in Appendix A.

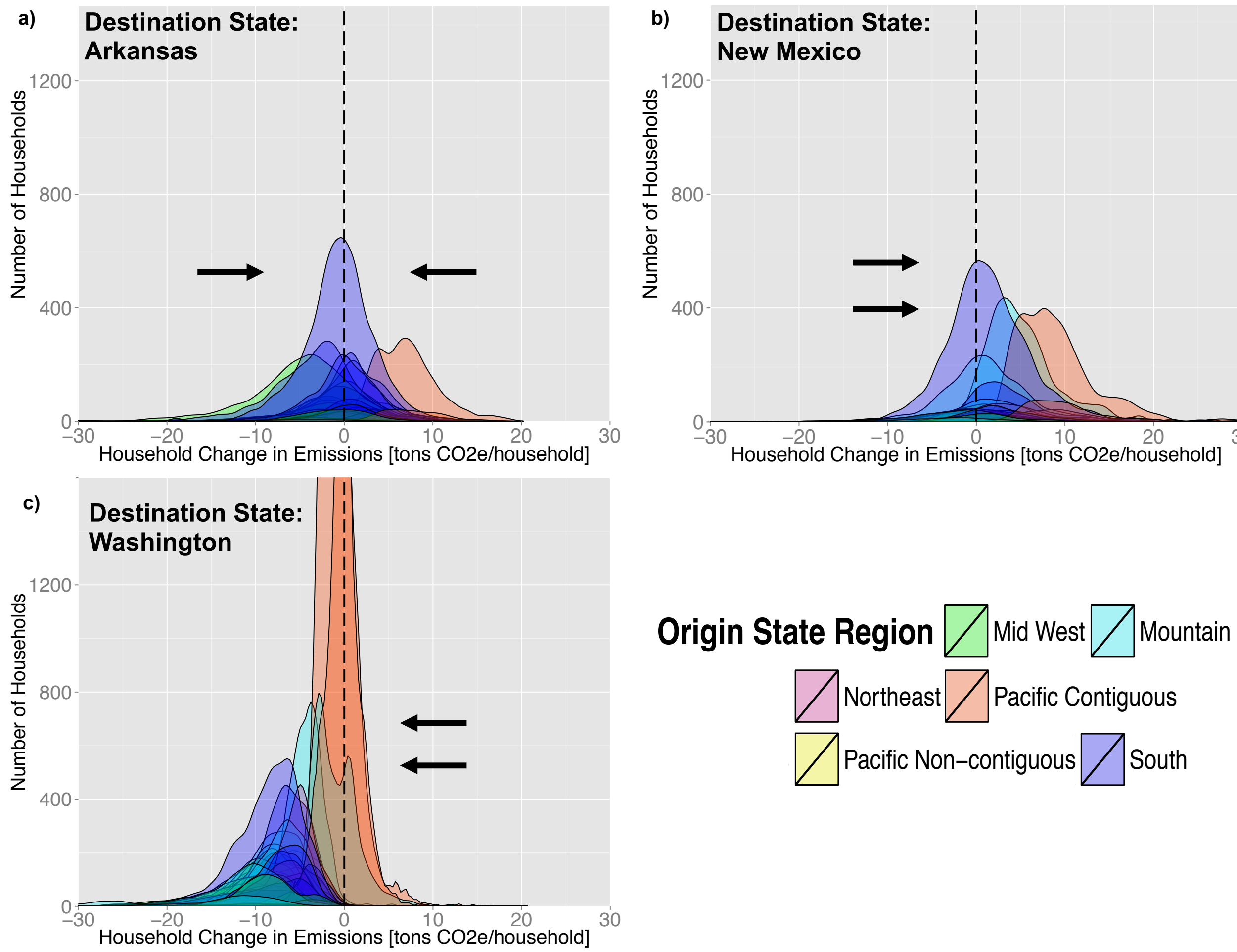


Figure 2-7 The distributions of expected change in residential emissions for all households moving to Arkansas, New Mexico and Washington. Each curve is the distribution for households moving from 49 other states and DC, colored by origin state Census region.

Differences in state residential emissions profiles are dominated by differences in state electricity grids but dampened (equalized) by the addition of natural gas and other fuels, shown in Figure 2-8. The figure shows the distributions of emissions changes for all households moving to Florida by origin state for (Figure 2-8a) emissions from all residential energy use and (Figure 2-8b) emissions from only residential electricity. In Figure 2-8b, many of the 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 in Figure 2-8a 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. Yet, the curves in Figure 2-8are still dominated differences in local electricity grids. The area under pink and orange curves, representing the origin states in the northeast and pacific, is primarily to the right of zero because those states have less carbon intensive electricity grids than Florida. This highlights the importance of managing the carbon intensive electricity grids in areas that continue to experience high net migration, like Texas and Florida.

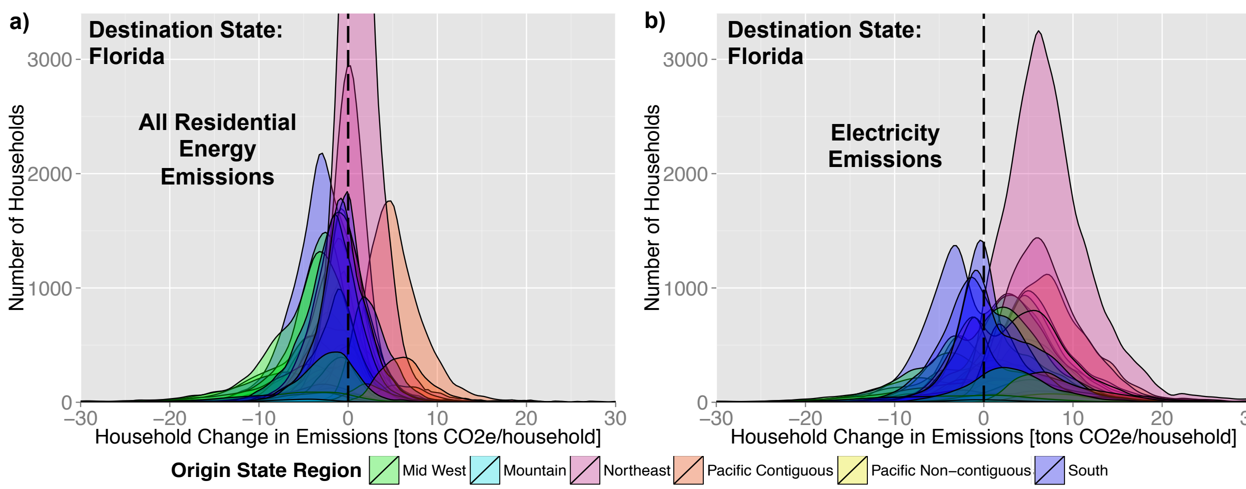


Figure 2-8 The distributions of expected changes in (a) all residential emissions and (b) electricity emissions for households moving to Florida. Emissions changes are driven by differences in electricity emissions, but dampened by the addition of emissions from other residential fuels.

2.4.2. Household Transportation Energy and Emissions

VMT per household in 2005 and 2010 varies widely over state. Estimates of VMT and emissions per household for select states are shown Table 2-2, full table shown in Appendix A. Annual average transportation emissions per household vary from 9 tons CO_2eq to in New York to 23 tons CO_2eq in Wyoming, compared to the US average household of 14 tons CO_2eq/year from household transportation use. US average household transportation emissions are larger than US average residential emissions, 10 tons CO_2eq/year, which was explained in the previous section.

Table 2-2 Average annual VMT and transportation emissions per Household in 2005 and 2010.

State	VMT per HH 2005	VMT per HH 2010	Transportation CO_2eq 2005 [tons/hh]	Transportation CO_2eq 2010 [tons/hh]	Emissions Change from 2005 to 2010 [tons/HH]
Arizona	27,130	25,730	14.23	12.80	-1.4
California	27,220	26,020	14.27	12.94	-1.3
Georgia	34,190	32,080	17.93	15.96	-2.0
Massachusetts	22,650	21,570	11.88	10.73	-1.2
Michigan	26,760	25,630	14.03	12.75	-1.3
Mississippi	38,920	36,890	20.41	18.35	-2.1
Montana	30,210	27,780	15.84	13.82	-2.0
New Mexico	32,930	33,100	17.27	16.46	-0.8
New York	19,330	18,240	10.14	9.07	-1.1
Pennsylvania	22,230	20,330	11.66	10.11	-1.5
Wyoming	44,200	42,940	23.18	21.36	-1.8
United States	26,910	25,890	14.11	12.88	-1.2

VMT per household decreases in almost all states from 2005 to 2010, which is consistent with decreasing VMT in the US over the past 10 years(Weber et al. 2010; Puentes and Tomer 2008).

Similar to the maps above, Figure 2-9 shows the sum of household transportation emissions for households moving to each state. The magnitude of emissions changes for household transportation is similar to that of emission changes for residential energy. The sum of emissions changes for household moving to states range from -500,000 tons CO_2eq for households moving to New York to +380,000 tons for households moving to Georgia. The total sum of transportation emission changes in the US is a given year is roughly +500,000 tons, similar to the total sum of residential emission changes. Like residential energy, households experience a range of emissions changes. Average households moving from Massachusetts to Wyoming experience an emissions increase of 12 tons CO_2eq/year/household, while average households moving from New York to California experience an emissions increase of 3 tons CO_2eq/year. The absolute value of all emissions changes experienced by households migrating in a given year is almost 7 million tons CO_2eq; however, emission increases and decreases balance to a relatively small value.

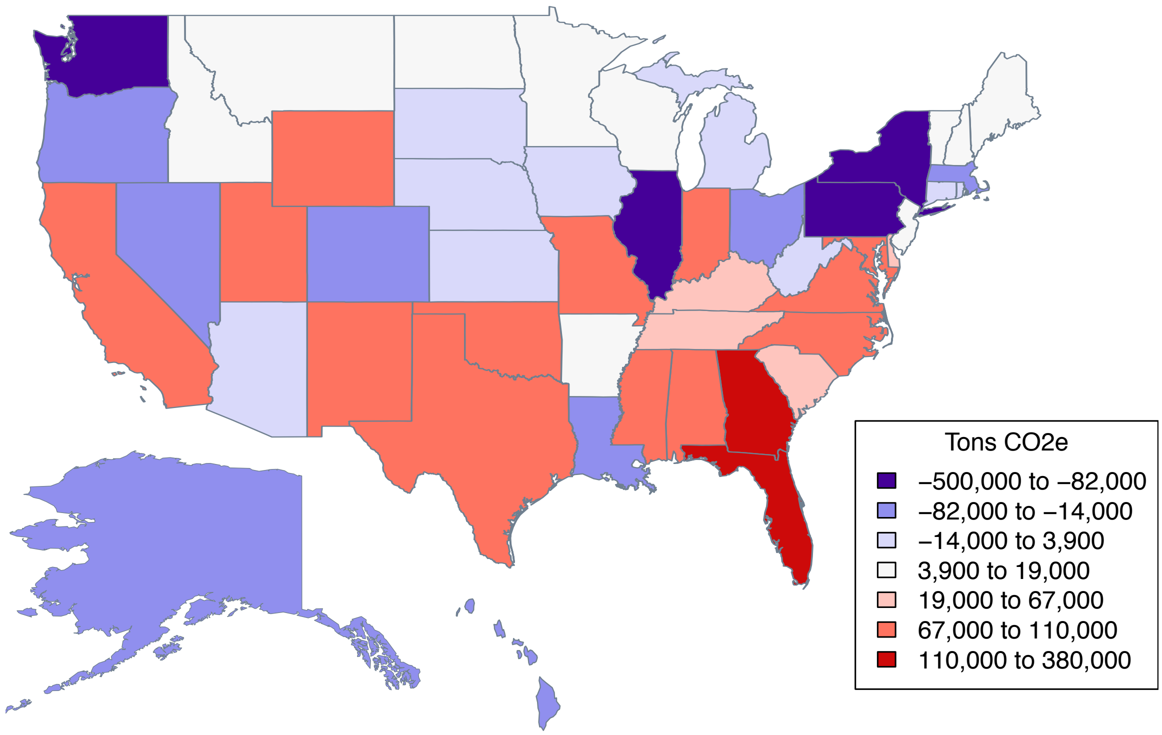


Figure 2-9 Sum of household transportation emission changes for households moving to individual states.

Table 2-3 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 2-3 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

2.4.3. Total Household Energy and Emissions

Total household emissions changes, which include residential and transportation emissions, are shown in Figure 2-10. The figure shows the sum of total household emissions changes for all households moving to each state.

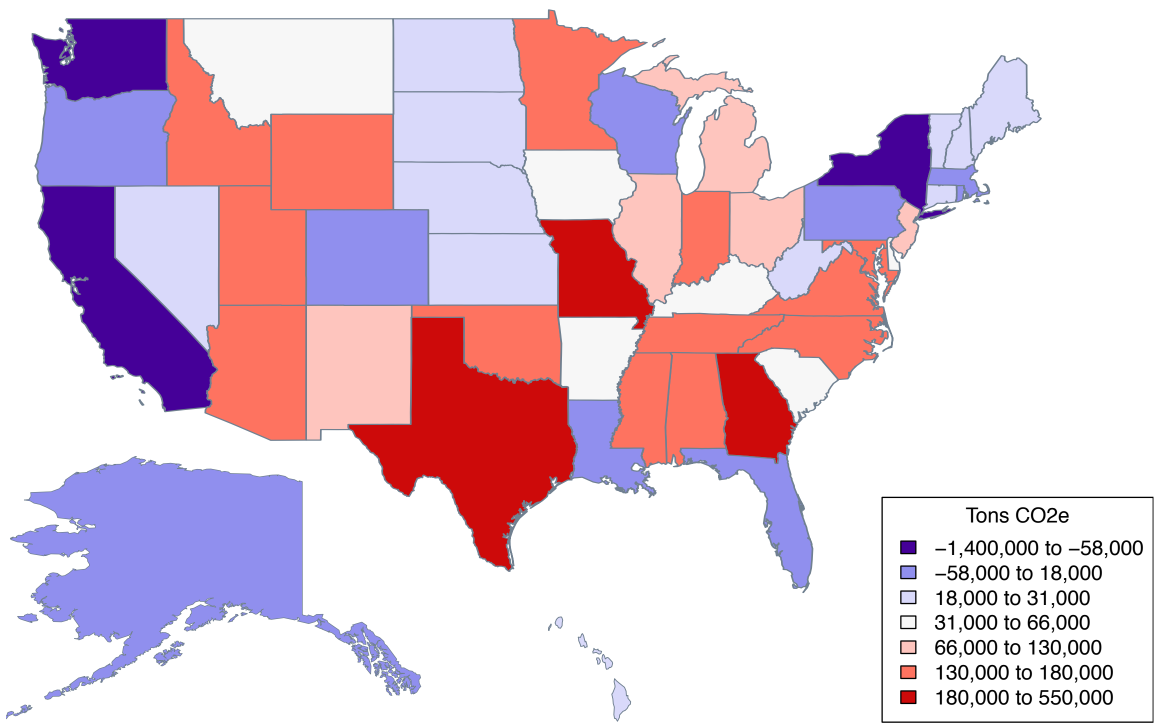


Figure 2-10 Sum of household emissions (residential and household transportation emissions) change estimate for households moving to states.

Household emission changes for some destination states are dominated by residential energy emissions, while other states are balanced by both residential and household transportation emissions. Emission sums for select states are shown in Table 2-4, a complete table is shown in Appendix A. Households moving to California experience modest transportation emission increases; however, they are far outweighed by the emissions savings from mild climates and a low carbon electricity grid. The sum of emissions for household moving to California remains almost 3 times larger than the next largest emissions sum, Georgia, who's migrating households experience a sum of +550,000 tons CO2eq. Emissions decreases experienced by all households moving to Florida are almost completely canceled by increases in transportation emissions.

In Northeastern and Pacific Northwestern states, households experience decreases in both household residential and transportation emissions, exacerbating the emissions savings they experience as a result of a move. Households moving to Texas, New Mexico, Wyoming, and most southern states, experience increases in both residential energy and transportation emissions.

Table 2-4 Total household emission sums for all households moving to select states. Complete Table shown in Appendix A.

	Residential	Household Transportation	Total Household
ARIZONA	212,000	1,840	214,000
CALIFORNIA	-1,550,000	107,000	-1,450,000
CONNECTICUT	27,900	-3,870	24,100
DELAWARE	18,600	30,700	49,300
FLORIDA	-347,000	306,000	-41,000
GEORGIA	172,000	378,000	550,000
ILLINOIS	321,000	-222,000	98,700
MASSACHUSETTS	-39,000	-87,000	-126,000
MISSOURI	205,000	99,500	304,000
NEW MEXICO	22,100	95,000	117,000
NEW YORK	-185,000	-495,000	-680,000
OKLAHOMA	34,100	123,000	157,000
OREGON	-188,000	-56,400	-244,000
PENNSYLVANIA	-126,000	-193,000	-320,000
TEXAS	203,000	93,200	296,000
WASHINGTON	-402,000	-173,000	-575,000
UNITED STATES	165,000	561,000	725,000

2.5. Limitations and Uncertainty

A limitation of this analysis is the characteristic differences of migrating households versus non-migrating households. 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, provided in the Appendix, 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. 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 many states is bimodal, peaking at both early twenties and retirement age, while age distributions of non-migrating households are more normal. Regressions, shown in the Appendix, 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. Data are not available to support (or examine) the assumption that households likely to move in the future also experience this shift in their origin state. However, an underlying assumption of our simulation is that a household's percentile of total energy use in both origin and destination state will be highly correlated, or a household's relative energy use behavior compared to other household in their state will not change drastically with a move across state lines. It is therefore inconsistent to apply this shift to destination state energy use but not origin state. The results of the model do not change when this shift is applied to both origin and destination state energy use, because we measure the difference in emissions; aggregate US emission changes over a year in the US remain slightly positive, but quite small.

We assume that a household's energy use in its origin state relative to other households in its origin state will be positively correlated with its energy use in its destination state relative to other households in its destination state. As correlation increases, distribution of household emission changes by migration flow become taller and narrower (shown in the Appendix) because more households are expected to experience emissions changes closer to zero; however, both state and US aggregate emission sums remain similar regardless of correlation values between 0 and 1. Uncertainty is also associated with IRS migration data, however we believe that this is much smaller than those driven by the energy use of migrating versus non-migrating households.

Sensitivity and uncertainty in this analysis also comes from electricity grid emission factors. Studies have show that significant uncertainty exists within different methods of estimating grid emission factors at regional and sub-regional levels (Marriott and Matthews 2005; Weber et al. 2010). Sub-region electricity trading occurs between states, which adds the uncertainty to the differences between state level electric grid estimates within the same region(Hawkes 2010; Marriott and Matthews 2005). This may inflate the importance of emission implications of cross state migration flows between states that often trade electricity, or that are member of the same interconnect. Appendix A shows summary statistics and figures for household emissions changes by destination state when using state, regional, and the average of state and regional emission factors. Most states show similar results; however, a few states that have both large regional migration flows and large differences between state emission factor estimates and regional emission factor estimates show different results. Distributions of household emission changes for these destination states, including Arizona and Idaho, tend to be shifted right but remain similar in shape. While using state emission factors does exacerbate the magnitude of emissions changes for a few states, it does not contribute to large uncertainty in aggregate US emission totals. The range of expected aggregate US emissions changes increases from 40,000 tons +/- 15,000 tons CO_2eq to 150,000 tons +/- 15,000 tons CO_2eq when switching from state emission factors to regional emission factors. Both numbers remain less than 1% of total annual US residential emissions. NERC regions were not used in this analysis. The use of NERC regions would likely dampen the importance of migration between western states, as most of the Pacific and mountain regions are part of the Western Interconnection.

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) (Siler-Evans, Azevedo, and Morgan 2012; Hawkes 2010). MEFs vary constantly as different generators with different emission intensities are required to meet demand at a given time, which result in different MEF estimates over hours, seasons, and regions. The difference between average MEFs and their corresponding AEFs vary from 2 - 35% over regions in the US (Siler-Evans, Azevedo, and Morgan 2012). MEFs are more appropriate than AEFs for estimating emissions implications of short term demand changes, such the implementation of an energy efficient lighting systems (Doucette and McCulloch 2011; Siler-Evans, Azevedo, and Morgan 2012) or battery electricity vehicle charging (Bettle, Pout, and Hitchin 2006; Doucette and McCulloch 2011) and have been shown to affect CO_2 emissions calculations as much as 50%(Hawkes 2010; Bettle, Pout, and Hitchin 2006). 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
- Long term infrastructure planning years ahead (Hawkes 2010; Siler-Evans, Azevedo, and Morgan 2012).

MEFs reflect short term systemic effects of electricity interventions (USDA Economic Research Service 2013; Hawkes 2010; Siler-Evans, Azevedo, and Morgan 2012). 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.

Households move to a different state for different reasons, and it is likely that specific types of moves likely have energy implications. These households may have uncorrelated energy use in their origin and destination states. For example, an elderly couple retiring and downsizing in a warmer location may move to a lower percentile energy use in their retirement state. There is no data to infer the flow size of types of moves to different states, but we can make casual observations about certain flows. For example, New York to Florida, one of the larger migratory flows in the US, is likely dominated by retirement moves.

While estimates presented in this analysis are uncertain for many reasons, we are confident that aggregate emission changes from migration in the US are close to zero but driven by many household increases and decreases grouped regionally. Even with the uncertainty present in this analysis it remains important to manage the electricity grid in areas that expect high immigration rates.

2.6. Forecasting and Implications for Energy Planning

Forecasting population growth and decline, both nationally and at smaller geographies, is an area fraught with uncertainty, and predicting future migration patters is perhaps the most uncertain component of such forecasts.

However uncertain predicting specific flow rates between states or regions is, households in the US have continued to follow the trend of moving south and west from the north east. If current migration trends continue, it is likely that we will continue to see total emissions changes at the national level balance to small net increases; however, this net balance relies on the migration of many households to a few low carbon regions. Households will likely continue to move to states where they are likely to produce more emissions from both residential energy and household transportation, especially Texas and the South Atlantic. As long as those moves are buoyed by migration to California and the pacific north west we are unlikely to see significant annual emissions increases from household mobility in the US alone. Large amounts of migration to California seem to be a likely trend the future, simply because of the sheer size of its population. Average net migration to California from 2004 – 2010 was net negative, more household moved out of California to other states than into California from other states, but the number of households moving there balanced emission flows.

These results may change as the carbon intensity of electricity grids evolve in the future. Many state are planning the decarbonization of their electricity production by creating Renewable Portfolio Standards (RPSs), also referred to as Alternative Energy Portfolio Standards (AEPSs). As of Jan 2012, 30 states have mandatory RPSs and 7 additional states have voluntary RPSs. Between 2000 and 2010, Texas, California, Florida, Georgia, Arizona and North Carolina accounted for 54% of the overall growth the US (US Census Bureau 2011). Of those 6 states, 4 have RPS and 2 do not, shown in Table 2-5.

Table 2-5 Renewable Portfolio Standard Goals for States with the Largest Growth

State	Goal
California	2011: 33% by 2020
Texas	2005: 5,880 MW by 2015
North Carolina	2007: 12.5% by 2021
Arizona	2006: 15% by 2025
	(Center for Climate and Energy Solutions, 2014)

RPS goals and policy designs vary widely across states, but represent some measure of how regional electricity grids may change in the future. The states that contributed the largest emissions increases from migration between 2005 – 2010 were Texas, Georgia and Missouri. While Georgia has no RPS, in 2008, Missouri set an RPS goal of 15% by 2021. California, which contributed the most to emissions decreases from migration, has some of the most aggressive goals, 33% by 2020. Washington and Oregon, which were also responsible for large emissions decreases, have goals of 15% by 2020 (a moderately aggressive goal) and 25% by 2525 respectively. Some states that contributed to moderate to high emissions reductions have RPS goals, like Minnesota and Illinois (Center for Climate and Energy Solutions, 2014). Most states in the South Atlantic however, do not have RPS goals and this region may see the smallest changes in electricity grid emissions while other states work to reduce grid carbon emissions. Emission increases from households moving to this region may be exacerbated in the future.

Household energy emissions examined in this analysis have two components, residential energy and household transportation energy. Maintaining the net zero emissions for migrating household involves balancing both components, which are sometimes opposing forces. From 2004 – 2005, residential emissions were slightly better balanced (netted slightly closer to zero) than transportation emissions, but it seems that that balance is more precarious and reliant on many moves to a low carbon grid in California.

2.7. Discussion

Residential emissions profiles and the shuffling of households to and from different areas contribute to changes and flows of total US GHG emissions. In a paradigm dominated by regional emissions planning, it is important to see how the interactions of many regional emissions goals and plans fit in to national emissions mitigation progress. Some cities have managed to reach reductions below business as usual projections or baseline inventory estimates even with growing population. However, some areas receive a high volume of migrants that produce more GHGs as a result of their move, so regional emissions reductions do not necessarily translate to national emissions reductions. While achieving regional reduction goals anywhere contributes to lower carbon future, emphasizing regional mitigation efforts for higher carbon areas with quickly growing populations driven by migrators from low carbon areas becomes more important for realizing national level emission reductions.

This analysis shows that, the current population shifts (mostly south and west) to different states does not significantly contribute to changes in net US GHG emissions. However the population shifts in the US can be categorized in different ways with different energy and emission implications associated with them. From 2010 – 2012, the population of non-metro counties declined for the first time is US history; birth rates in these area are not large enough to counter net migration rates (Crossett et al. 2004; USDA Economic Research Service 2013). Population shifts from non coastal to coastal regions has also been documented (Glaeser and Kahn 2010; Crossett et al. 2004; Jones and Kammen 2014; Min, Hausfather, and Lin 2010). Population shifts from rural to urban centers notably has effects of transportation emissions while population shifts from non-coastal to coastal regions likely has heating and cooling implications.

In this analysis, changes in emissions were only considered for one year. When households stay, these emissions changes will likely continue for many years. A household experiencing an annual increase of 7 tons of CO_2eq by making a long term move to a new carbon-intensive state will experience that change every year they remain in the new state. While state-to-state migration doesn't significantly contribute to year-to-year changes in US emissions, they may become more important when evaluated over longer periods. In areas where migrating households often experience emissions increases, regional and local policies to encourage population growth without targeted residential GHG emission mitigation policies could encourage locking in emission increases into infrastructure.

3. ENERGY AND EMISSIONS IMPLICATIONS FROM COUNTY-COUNTY MOBILITY IN PENNSYLVANIA

3.1. Background

Of the 35 – 40 million people who change address in the US every year, roughly 57% stay within the same county, 19% move across state lines, and 20% move to a different county within the same state(US Census Bureau 2005). The previous chapter examined the almost 20% of migrating household that move across state lines. This chapter examines the 20% of households that move between counties within a state, using Pennsylvania as a case study.

Many studies have shown how household carbon footprints vary over zip codes, cities, and states across the US (Bento et al. 2005; Glaeser and Kahn 2010; Brownstone and Golob 2009; Jones and Kammen 2014; S. Lee and Lee 2014; Min, Hausfather, and Lin 2010; Chao and Qing 2011; Transportation Research Board). Differences in household carbon footprints are associated with differences in climate zone, the carbon intensity of regional fuel mixes, income, and other factors. Some of these factors, such as climate zone or carbon intensity estimates of the regional electricity grids, vary little within most states. However, household carbon footprints are equally driven by factors that vary at sub state geographies, such as urban form and population density. The last chapter described emission changes that households experience when moving to and from different states; based on those results, we expect that households moving to and from counties with different levels of urbanity will also experience emission changes.

There is a large body of work exploring the effect of urban form and population density on personal transportation behavior. Most generally conclude that increasing urbanity and population density is associated with lower annual VMT (vehicle miles traveled) and lower residential transportation energy and emissions (Brownstone and Golob 2009; Bento et al. 2005; S. Lee and Lee 2014; Chao and Qing 2011; Transportation Research Board). Brownstone and Golod, for example, showed that a decrease in residential population density of 1000 housing units per square miles is associated with an increase of both 1200 miles driven and 65 gallons of fuel per year (Brownstone and Golob 2009). Others found that doubling population weighted density is associated with a 48% reduction in household travel CO_2 emissions(S. Lee and Lee 2014). Some of these studies find that an increase in density results in, not only a decrease in VMT, but also a decrease in the likelihood of owning SUV's and pickup trucks, and thus an increase in fuel economy.

Similarly, many have studied the effects of urban form and population density on residential energy use (Ewing and Rong 2008; Bhat and Sen 2006; Brownstone and Golob 2009; S. Lee and Lee 2014). In these studies, household transportation energy is often found to be more sensitive to urban form than residential energy; however, this relationship is not insignificant. Urban form affects residential energy use through both housing stock/choices and, to a lesser extent, the urban heat island (UHI) effect. Ewing and Rong find that families are seven times more likely to live in a multifamily unit rather than in compact counties than in sprawling counties. This finding that has significant energy consequences, as they also report that comparable households consume 54% more energy for space heating and 26% more energy for space cooling when living in single family detached homes rather than multi family units (Ewing and Rong 2008).

From 2006 - 2010 central metropolitan counties in the US experienced less population growth than outlying counties; however, over 2010 - 2013 core counties experienced a higher growth rate than outlying counties. The largest contributor to population gains in 45 of the 50 largest metropolitan areas was net migration, rather than natural growth(Toppo and Overberg 2014). These trends were also observed in Pennsylvania. The US contains 3,148 counties; accounting for all flows between those counties presents over 9.9 million possible flows. The American Community Survey

(ACS) 2010 5-year migration estimates report that on average from 2005 – 2010, there are 241,559 non-zero annual flows between counties that account for over 17 Million people. The largest 60,000 county-county flows include 80% of the total migrants. However these flows still draw from almost all counties. They represent 2,977 destination counties and 2,913 origin counties, where 2,858 counties are both origin and destination counties those groups. Because the largest flows are spread over many counties, there is no clear balance between accounting for the most migrants and eliminating data problems of estimating or modeling metrics for all 3,148 counties. Additionally, no comprehensive national data exists that describing residential transportation consistently for all counties. However, there is privately accessible data from which we can derive vehicle VMT in Pennsylvania, by county. This analysis will use Pennsylvania as a case study and focus on the household transportation and residential energy use of roughly 300,000 migrants that move between all 67 counties in Pennsylvania annually.

From 2006 - 2011 roughly 120,000 households moved between counties in Pennsylvania every year, roughly 2.5% of the total household in PA. Non-zero migration flows between counties in Pennsylvania range from a few households moving between rural counties to 5,000 households moving from Philadelphia County to Montgomery County, a wealthy suburban county of Philadelphia. The largest flows within Pennsylvania are those describing households moving to or from the largest urban centers Philadelphia, located in Philadelphia County, and Pittsburgh, located in Allegheny County. 39,000 households, or 33% of migrating households move to or from these two counties every year. Figure 3-1 shows the net number of households migrating to counties in Pennsylvania in 2009. Large urban centers experienced net negative migration, while most suburban counties experienced net positive migration.

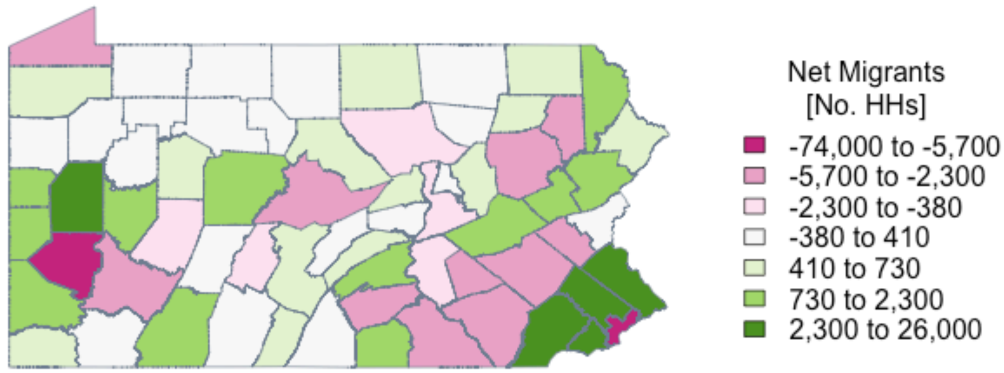


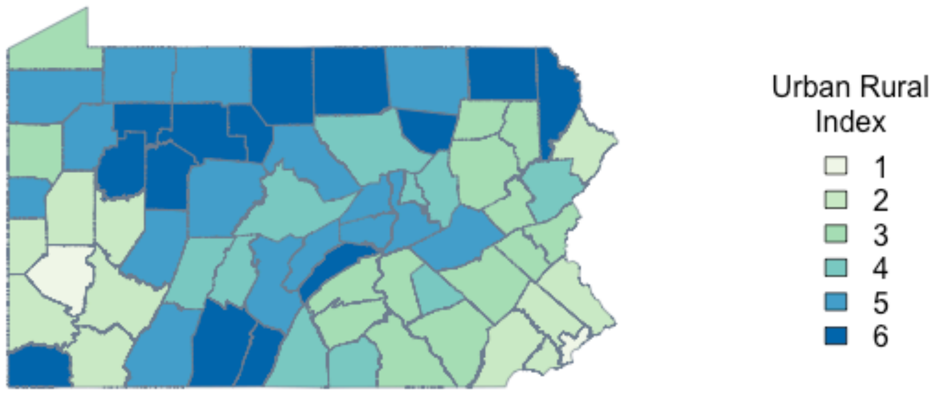
Figure 3-1 Net Migrating Households into Counties in Pennsylvania in 2009.

Pennsylvania counties span all 6 urban-rural classifications (UR Index), as defined by the National Center for Health Statistics (Ingram DD 2014), shown in Table 3-1 and Figure 3-2a. UR Indices range from 1, the most urban, to 6, the most rural, and are defined by population size of the county and the Metropolitan Statistical Area (MSA) that the county lies in or around. MSAs are regions, defined by the Office of Management and Budget (OMB), with large central population densities and close economic ties.

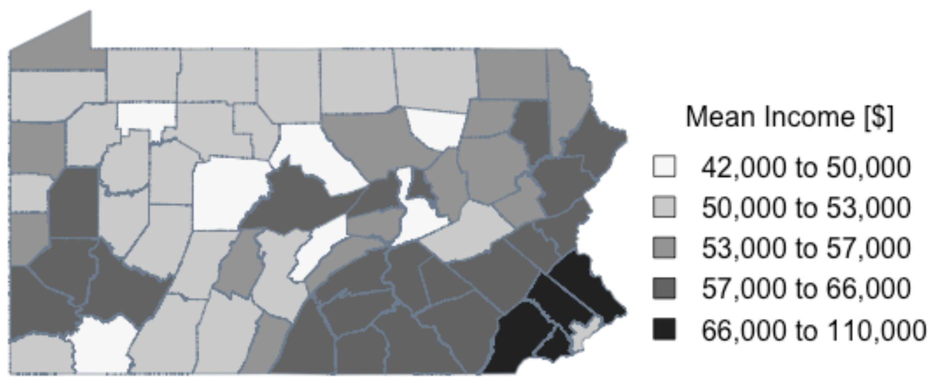
Table 3-1 County Urbanity in Pennsylvania

UR Index	Classification	No. of Counties in PA	% Population	Example Counties
1	Large Metro, Central	2	22%	Philadelphia and Allegheny County
2	Large Metro, Fringe	11	29%	Beaver and Butler County
3	Medium Metro	14	28%	Erie County
4	Small Metro	10	9%	Franklin County
5	Micropolitan	16	9%	Somerset County
6	Noncore	14	3%	Bedford County

Mean household income, shown in Figure 3-2b, also varies widely by county, which is correlated with urban-rural index. Mean Household income varies from $42,000/year in very rural counties to over $100,000/year in wealthy suburban counties of Philadelphia.



a)



b)

Figure 3-2 a) The urban-rural index of counties in Pennsylvania. Rural counties are darker while urban counties are lighter. b) The mean household income in 2009 dollars.

3.2. Data

The major sources of data used in this analysis include migration data, residential energy use data, and household transportation data (consisting of Pennsylvania state vehicle inspection data which are used to derive annual VMT by county).

3.2.1. Migration Data

County migration data is available from 2 main sources: the Internal Revenue Service (IRS) area to area migration files(Internal Revenue Service Statistics of Income Division), published annually, and the ACS 2007-2011 5 year County-to-County Migration Flows(US Census Bureau 2012a). IRS data is based on the change of address field in individual income tax returns and reports estimates for the number of migrating households, based on the number of returns filed, and the number of migrating individuals, approximated by the number of personal exemptions claimed. The ACS is a continuous national survey that collects demographic, economic, social, and housing data conducted by the US Census bureau to fill in between the Decennial Census. While state-to-state migration estimates are published annually, county-to-county migration flow estimates are only provided for 5-year ACS samples. Migration flows are derived from the survey question, "Did this person live in this house or apartment one year ago?" and estimates can be described as average "yearly flows over a 5-year period" (US Census Bureau 2009).

In order to protect the privacy of taxpayers, the IRS suppresses data on flows with small numbers of households; county flows with at least 10 households are published, but smaller flows are suppressed to zero(Gross 2006). All migrating households are accounted for in aggregate summary totals, such as the total migrating to a certain county from the Northeast Census region or from the same state. Data suppression becomes a problem when tracking county-county moves across states, because many flows are less than 10; however, reported flows are sufficient to track migrating households within a state. For example, in the 2010 data, origin and destination counties are disclosed for only 58% of household migrating to Pennsylvania from other states in the US, while origin and destination counties are disclosed 94% of households migrating within Pennsylvania. This analysis uses the 2005-2010 and 2007-2011 5-year ACS samples to fill in data gaps from IRS files. While some census mobility data estimates movers over a 5-year period, both the ACS and IRS migration data estimate movers over a 1-year period and are thus comparable. The process of using reported ACS flows as supplementary migration data is explained in the methods section.

3.2.2. Residential Energy Data

Residential energy data was available from the ACS and was validated with US Energy Information Administration's (EIA) 2009 Residential Energy Consumption Survey (RECS). RECS is a residential energy survey conducted by the EIA every few years and collects household characteristic, energy use, and expenditure data to create a representative sample of household in the US. The 2009 RECS sampled 12,083 households from 16 states, including Pennsylvania. The RECS microdata provides, for individual households, annual electricity, natural gas, kerosene, LPG, and fuel oil use in physical units, energy units, and total expenditure in dollars.

While RECS is widely used for its comprehensive data, the smallest indicator of household geography is at the state level (or RECS domain, a group of states defined by RECS). RECS does not provide smaller geographic identifiers such as county or zip code. This makes exploring the differences in household energy at sub-state geographies impossible without additional modeling and assumptions.

The US Census Bureau, however, continuously surveys households in all geographic areas of the US and publishes data in the form of the ACS. While these surveys do not contain comprehensive energy use data, like RECS does, it includes data on economic, social, and household characteristics that include utility expenditure data. The ACS samples 1 in 40 addresses every year, rather than 1 in every 6 households every 10 years like the decennial census. Continuous sampling allows the ACS to provide yearly and multiyear estimates at different geographic areas. 1-year estimates (based on 12 months of data) are available for areas with populations larger than 65,000, while 3-year estimates (based on 36 months of data) are available for areas with populations of more than 20,000. 5-year estimates (base on 60 months of data) are available down to Census tract levels. ACS defines data by geographic areas known as Public Use Microdata Areas (PUMAs). PUMAs are areas of at least 100,000 residents and are combinations of adjacent counties or census tracts(US Census Bureau 2009).

ACS energy expenditure data is in the form of self-reported monthly electricity bills, monthly natural gas bills, and annual fuel costs of "other fuels". It also indicates the household primary heating fuel, which identifies fuels by the following: electricity, natural gas, liquid petroleum, fuel oil or kerosene, wood, coal or coke, solar, other, or indicates that no heating fuel was used. The process of translating the total cost of "other fuels" to energy use and emissions of specific residential fuels is discussed in Section 2.3. The ACS technical documentation advises caution when using such data for energy related analysis citing the limitations associated with self-reported utility data(Claxton 1984; Payne 2000); however, other studies have successfully used ACS energy data when calculating household carbon footprints (Glaeser and Kahn 2010; S. Lee and Lee 2014). 2009 1-year ACS PUMS (Public Use Microdata Samples) for households residing in PA and 2009 RECS microdata for households residing in PA were used to supplement the ACS utility data.

3.2.3. Household Transportation Data

Estimates of annual VMT, by county, were derived from Pennsylvania annual state inspection files, obtained from a private company. These files consist of data collected during a vehicle's required annual state safety inspection. This includes anonymized vehicle data, including but not limited to vehicle inspection numbers (VINs), inspection date, county of vehicle registration, and odometer reading at the time of inspection, in addition to the safety inspection data, such as brake pad thickness. This analysis used annual files from 2007-2011 that vary from 700,000 – 1 million observations. While these files do not include all vehicles inspected and registered in Pennsylvania, they include a sample of vehicles from all counties in Pennsylvania. Many vehicles appear multiple times in a single year or over the 5-year period. Annual VMT was derived for individual vehicles from current odometer and inspection date data.

3.3. Methods

The change in emissions from migrating households was estimated as the difference between a household's total emissions (residential and household transportation emissions) in its origin and destination counties. Residential emissions in origin and destination counties were estimated individually for all households migrating between counties in Pennsylvania in a given year while transportation emissions were estimated for entire flows between counties. Monte Carlo analysis was used to incorporate uncertainty into estimates.

3.3.1. Migration Flows

IRS Migration data was arranged into 67x67 origin-destination (OD) matrices representing the origin and destination counties of migrating households, then IRS OD matrices were supplemented with the 5-year average ACS migration data. The flow data for a destination county was only supplemented if IRS data reported less than 75% of the county-county flows terminating in that county, about 13 counties per year. ACS flows, which are reported in units of individuals migrating, were converted to units of households using estimates for migrating individuals per household for each county and derived from IRS individual and household estimates for each year. In these underreported counties, specific flows were supplemented, according to the bullets below, only if nonzero flows in ACS were reported as zero in the IRS data.

- IRS zero flow estimates were replaced with the reported ACS flow if the ACS flow was less than 10 households.

- IRS zero flow estimates were replaced with 10 if the reported ACS flow is greater than 10 households. This would indicate that the average flow in the 5-year ACS data is larger than the annual flow in the IRS data. However, if the annual flow were greater than 10, it would be reported as non-zero in IRS.

We assume flows greater than 10 households are not suppressed and thus reported as nonzero in the IRS data. OD matrices, noting replaced flow data, percent reported by IRS data, and percent reporting by supplemented data are shown the appendices. In both the residential energy model and the transportation model the number of households in a migration flow, N_{Hij}, is a value varied between IRS reported flow data and the IRS supplemented data.

3.3.2. Residential Energy

First, ACS utility expenditure was converted to estimate household energy use, which was compared and validated using RECS microdata. RECS representative weights, ACS representative household weights, and ACS household income adjustments were used as appropriate. The average price of electricity in 2009 in the residential sector was calculated from the 2009 RECS microdata by regressing annual electricity use in kWh on annual electricity expenditure in dollars; similar analyses were conducted for natural gas, liquid petroleum gases, fuel oil, and kerosene, shown in the Appendix B. The average price of coal for commercial and institutional sectors in 2009 was obtained from the EIA 2009 quarterly coal reports (US Energy Information Administration 2010). Average fuel price estimates were used to convert household energy expenditure to household of energy use estimates in physical units and BTUs. The prices of residential fuels (derived from 2009 Pennsylvania RECS microdata) and lifecycle emission factors used are shown in Appendix B.

Monthly electricity and natural gas utility bills were multiplied by 12 to approximate annual expenditure. ACS surveys are conducted continuously and ask for the previous month's utility bill.

However, monthly utility bills vary with seasons and temperature, and ACS does not indicate for which month or season utility bills are reported. Because annual energy use estimates for some households are estimated from low-energy months while others are estimated from high-energy month, the spread of annual household energy use estimated by ACS is slightly wider, yet still comparable to those estimated by RECS, shown in Figure 3-15a for households in rural Pennsylvania. The seasonal variability of energy bills are likely dampened by households that use utility budget payment plans, where the utility company overcharges the customer in low energy months and under charges the customer in high energy months in order to equally distribute estimated monthly utility bills over the given year. Annual electricity and natural gas use, for a household *n*, was calculated according to Equation 7 and Equation 8.

$$E_{kWh}^{n} = 12 \times U_{kWh}^{n} \times P_{kWh}$$

Equation 7

Where

E_{kWh}^{n} is annual electricity use, in kWhs , for household *n* in ACS microdata;

U_{kWh}^{n} is reported monthly electricity utility bill, for household *n*;

P_{kWh} is average price of electricity paid by residential customers in PA in 2009, estimated from RECS microdata in units of $/kWh.

$$E_{NG}^{n} = 12 \times U_{NG}^{n} \times P_{NG}$$

Equation 8

Where:

E_{NG}^{n} is annual natural gas use, in cu. ft., for household *n* in ACS microdata;

U_{NG}^{n} is reported monthly gas utility bill, for household *n;*

P_{NG} is average price of natural gas paid by residential customers in PA in 2009, estimated from RECS microdata in units of $/cu. ft..

The ACS other fuels variable estimates the annual cost of fuels other than electricity and natural gas which can include LPG, fuel oil, wood, coal or other unnamed sources. Pennsylvania RECS microdata was used to make inferences about Pennsylvania energy use when ACS data was not sufficient. These inferences are for all of Pennsylvania, because RECS does not provide geographic information below the state level. The other fuels expenditure was used to estimate other fuel energy use using a household's primary heating fuel. For households that reported using LPG, fuel oil, or coal/coke as primary heating fuel, other fuels expenditure was assumed to be 100% reported primary heating fuel. For example, we assume a household reporting propane as it's primary heating fuel, would spend 100% of its other fuels expenditure on propane.

Other fuels expenditure for remaining households is assumed to be 40% LPG and 60% fuel oil, as RECS microdata shows that 40% of total LPG, fuel oil and kerosene costs are spent on LPG by Pennsylvania households. The non-trivial process of translating other fuel expenditure was not necessary for the state analysis in Chapter 2. In Chapter 2, energy use data from RECS was used, which provides the household energy use of all fuels individually, unlike the ACS data, which lumps the fuel expenditure of other fuels into one variable.

Annual household energy use of other fuel, for household *n*, is calculated according to Equation 9 and Equation 10. Wood use is excluded from this analysis. Validity of and uncertainty associated with residential fuel assumptions and data are discussed in the uncertainty section.

$$E_k^n = Exp_k^n \times P_k$$

Equation 9

Where:

E_k^n is annual use of fuel k, in physical units , for household *n*, using fuel k as primary heating fuel, where fuel *k* is fuel oil, LPG, or coal;

Exp_k^n is reported annual other fuel expenditure, for household *n*;

P_k is average price of fuel *k* paid by residential customers in PA in 2009, estimated from RECS microdata in units of $/physical unit.

$$E_{Other}^n = Exp_{Other}^n \times P_{Other}$$

Equation 10

Where:

E_{Other}^n is annual other fuel use (assumed to be 60% fuel oil and 40% LPG), in gallons, for household *n*, not reporting fuel oil, LPG, or coal as primary heating fuel;

Exp^n_{Other} is reported annual other fuel expenditure, for household *n*;

P_{Other} is average price of fuel oil and LPG paid by residential customers in PA in 2009, estimated from RECS microdata in units of $/gallon.

GHG emissions were calculated according to Equation 11 using energy use estimates, life cycle emission factors for residential fuels, and lifecycle emission factor for electricity from the PA grid, shown in Appendix B.

$$Em^n = \sum_k E^n_k \times C_k$$

Equation 11

Where:

Em^n is household *n*'s annual emissions from residential electricity and fuel use;

E^n_k is household *n*'s annual energy use of fuel *k*, where *k* includes natural gas, fuel oil, LPG, coal, and other (the average of LPG and fuel oil);

C_k is the life cycle emission factor for fuel, *k*.

Household data is separated into county distributions of household data using ACS PUMA geographies. Because a singe PUMA may encompass 2 counties, some county distributions are identical. For example a single PUMA represents Cameron County, Pike County, McKean County, and Potter County. 14 PUMAs represent 37 counties that do not have a unique PUMA representation. The remaining counties are represented by one or more unique PUMAs. Other county distributions contain microdata from multiple PUMAs.

The energy use of migrating households in their origin and destination counties was estimated using a process of resampling energy use and emissions data for single households from the 2009 ACS PUMS. The change in emissions for a migrating household is estimated as the difference between a household's annual emissions from living in origin and destination counties for a year. Similar to the methods presented in Chapter 2, the total changes in emission for all households migration to and from counties in Pennsylvania were calculated using two methods; the first relates household energy use in origin and destination counties by percentile of energy use measured in BTUs, while the second relates household energy use in origin and destination counties by household income.

For a single household using the BTU method, a pair of correlated random uniform numbers between 0 and 1 (correlation of about 0.8) were generated to represent a household's percentile of total energy use in both origin and destination county, measured in total BTUs per year. We assumed these values are highly correlated because in most cases, it is likely that a migrating household's energy habits, such as willingness to use energy to provide comfort (like space heating or air conditioning) relatively compared to other households in the same county would be fixed. Correlated uniform numbers were created by randomly generating correlated random normal variables then transforming them to uniform variables using cumulative Gaussian distribution functions. Using the correlated uniform variables that represent percentiles of total energy use, 2 observations are drawn from the ACS data, to approximate energy use behavior of the household in both the origin and destination county. Each household sampling draws complete data for a household observation in ACS including electricity, natural gas, and other fuels explained above.

For a single household using the household income method, a household is randomly sampled from destination county distribution. Using the reported household income in it's destination county, the household is matched with a similar household in the origin county distribution containing the same number of household members and closest income. The destination household income was varied +/- 5% to incorporate uncertainty and avoid re-matching with the same household each model run.

Results from both methods are shown in this chapter. For either method, energy use observations for all households in origin and destination counties were retained and the change in residential emissions were calculated by Equation 12.

$$\Delta Em_{resid}^{n} = Em_{j}^{n} - Em_{i}^{n}$$

Equation 12

Where:

ΔEm_{resid}^{n} is household *n*'s change in residential emissions as a result of a move;

Em_{j}^{n} is household *n*'s annual emissions in its destination county;

Em_{i}^{n} is household *n*'s annual emissions in its origin county.

For a year of migration data, this process is repeated, using one of the methods above, roughly 120,000 times, to simulate the changes in energy use and emissions a household may expect when moving to a different county according to the OD matrices mentioned previously. The energy use and emissions for each household in its origin and destination counties as well as the expected change the household experiences from the move is retained for later analysis.

Results shown in this chapter reflect the BTU method, where the relationship between a household's energy use in its origin and destination counties is established by its percentile of total energy use measured in BTUs. A comparison and discussion of the income method is included in the uncertainty section.

3.3.3. Household Transportation

Pennsylvania state inspection data, was used to calculate annual VMT and fuel use by county. For all 5 years of data, vehicles, identified by unique VIN, with two or more unique observations of inspection dates (more than 80 days apart), relative odometer readings, and registration counties were retained for the analysis. The changes in odometer readings between inspection dates were normalized to represent a change in 365 days to estimate normalized, annual VMT. If there were enough observations for a specific vehicle to produce multiple annual VMT estimates, these estimates were averaged to obtain single annual VMT estimates for the vehicle. EPA combined fuel economy was derived from the VIN and used along with annual VMT estimates to estimate annual fuel use per vehicle. Annual VMT and fuel use estimates were separated by county of vehicle registration to form county specific empirical distributions of annual VMT and fuel use per vehicle.

For household transportation, the change in energy use can be described as the difference in vehicle fuel used in origin and destination county for the number of households in the flow. The same households will likely own a different number of vehicles with different fuel economies in origin and destination county, because vehicle ownership per household and average fuel economy of the fleet varies by county. The number of vehicles for the households in a migration flow in the origin county, N_{Vi} and in destination counties, N_{Vj}, was estimated as the number of households in the migration flow, N_{Hij}, times the total number vehicle registrations in the county in

2009(Pennsylvania Department of Transportations 2009) divided by the total number of households in the county, rounded to the nearest integer.

$$N_{Vi} = N_{Hij} \times \frac{Total\ Vehicle\ Registrations_i}{Total\ Number\ of\ Households_i}$$

Equation 13

Where, N_{Vi} is rounded to the nearest integer.

The total annual fuel use, F_i, from all households, N_{Hij}, in their origin county, i, is the sum of the individual vehicle fuel use of N_{Vi} randomly sampled vehicles from origin county empirical fuel use distribution. F_j, the total annual fuel use from all households, N_{Hij}, in their destination county, j, was calculated similarly, and the change in fuel use, ΔF_{ij}, is calculated according to Equation 14.

$$\Delta F_{ij} = F_j - F_i$$

Equation 14

Where

F_i is the total annual fuel use of households N_{Hij} in county i;

F_j is the total annual fuel use of households N_{Hij} in county j;

ΔF_{ij} is the change in total annual fuel use of households N_{Hij} moving from county i to county j.

Emissions from personal transportation are calculated using fuel estimates and the same lifecycle fuel emission factors used in Chapter 2, according to Equation 15

$$\Delta Em_{ij}^{trans} = C \times (F_j - F_i)$$

Equation 15

Where:

ΔEm_{ij}^{trans} is the change transportation emissions for households N_{Hij} migrating from county i to county j;

C is the lifecycle emission factor for gasoline;

F_i is the Total annual fuel use of households N_{Hij} in county i;

F_j is the total annual fuel use of households N_{Hij} in county j.

3.4. Energy Use in Pennsylvania

3.4.1. Residential Energy Use

Residential fuel use varies widely within Pennsylvania by county and urbanity index. Except for a few outlying counties that are both very rural and have a high percentage of homes heated by electricity or natural gas, such as Greene, Elk, Clarion, and Jefferson Counties, the percentage of homes heated by electricity or natural gas decreases with increasing ruralism, shown in Figure 3-3 and Table 3-2**.** Table 3-2 shows the percentage of homes using different fuels as the primary heat source for select counties in Pennsylvania. Urban counties are dominated by households using electricity and natural gas for heating, while very rural counties are dominated by homes using LPG and fuel oil for heating. The percent of homes heated by electricity or natural gas ranges from 96% in Allegheny County to only 15% in Sullivan. Some rural counties contain a significant percent of homes using wood or coal as a primary heating fuel. Energy and emissions from residential wood burning and not included in this analysis, which is explained in Section 3.6.

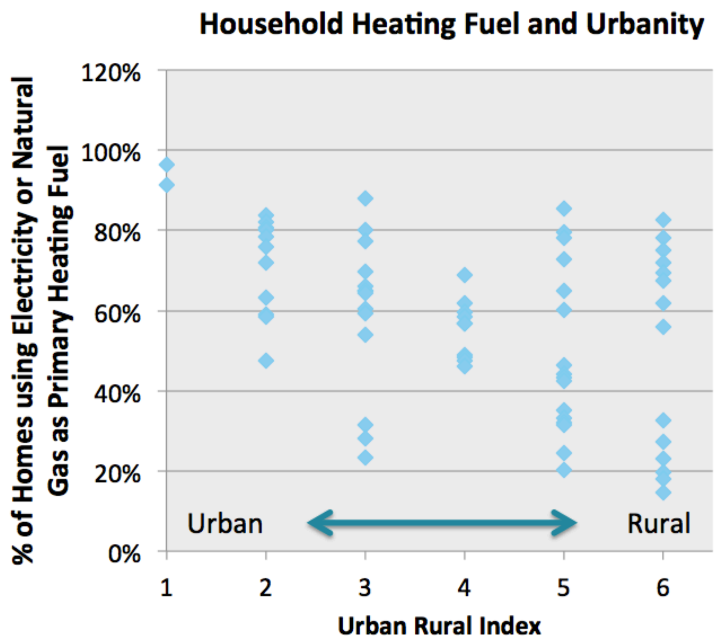


Figure 3-3 The Percent of homes using electricity or natural gas a primary heating fuel by county urban-rural index. Rural counties in Pennsylvania have a lower percentage of homes using electricity and natural gas as primary heating fuel than urban counties in Pennsylvania.

Table 3-2 shows the percentage of homes using fuels as primary heat source for select counties in Pennsylvania. Urban counties are dominated by households using electricity and natural gas, while very rural counties are dominated by homes using LPG and fuel oil heating. The percent of homes heated by electricity or natural gas ranges from 96% in Allegheny County to only 15% in Sullivan. Some rural counties contain a significant percent of homes using wood or coal as a primary heating fuel. Energy and emissions from residential wood burning are not included in this analysis, which is explained in the uncertainty section.

Table 3-2 The percent of homes using different fuels as the primary heating fuel in select counties. Complete Table shown in Appendix B.

	Urban Rural Index	Nat Gas	Electricity	LPG	Fuel Oil	Wood	Coal	Other (Solar, other, none)	% Utility Gas or Electricity	% LPG or Fuel Oil	% Wood, Coal, Other (not solar or None)
Allegheny County	1	86%	11%	1%	2%	0%	0.0%	0.6%	96%	3%	1%
Philadelphia County	1	79%	12%	1%	7%	0%	0.1%	0.6%	91%	8%	0%
Erie County	3	79%	8%	4%	4%	3%	0.1%	1.4%	88%	8%	4%
Washington County	2	66%	17%	2%	11%	2%	0.2%	0.6%	84%	13%	3%
Clarion County	6	74%	8%	4%	5%	5%	0.8%	1.8%	83%	9%	8%
Beaver County	2	70%	12%	3%	12%	2%	0.2%	0.5%	82%	15%	3%
Mercer County	3	64%	16%	2%	12%	4%	0.4%	1.5%	80%	14%	6%
Butler County	2	66%	15%	4%	11%	3%	0.3%	0.7%	80%	16%	4%
Lawrence County	5	59%	20%	2%	15%	2%	0.4%	0.8%	80%	17%	3%
Wyoming County	3	3%	20%	15%	47%	9%	4.8%	0.6%	23%	62%	15%
Juniata County	6	2%	21%	6%	48%	19%	2.8%	0.9%	23%	54%	22%
Huntingdon County	5	9%	12%	2%	59%	13%	3.4%	1.8%	20%	61%	18%
Bedford County	6	4%	16%	3%	60%	13%	3.7%	1.0%	20%	62%	18%
Sullivan County	6	2%	13%	6%	53%	20%	4.9%	1.8%	15%	59%	27%
Pennsylvania	-	**53%**	**20%**	**4%**	**22%**	**3%**	**1%**	**0.8%**	**73%**	**26%**	**4%**

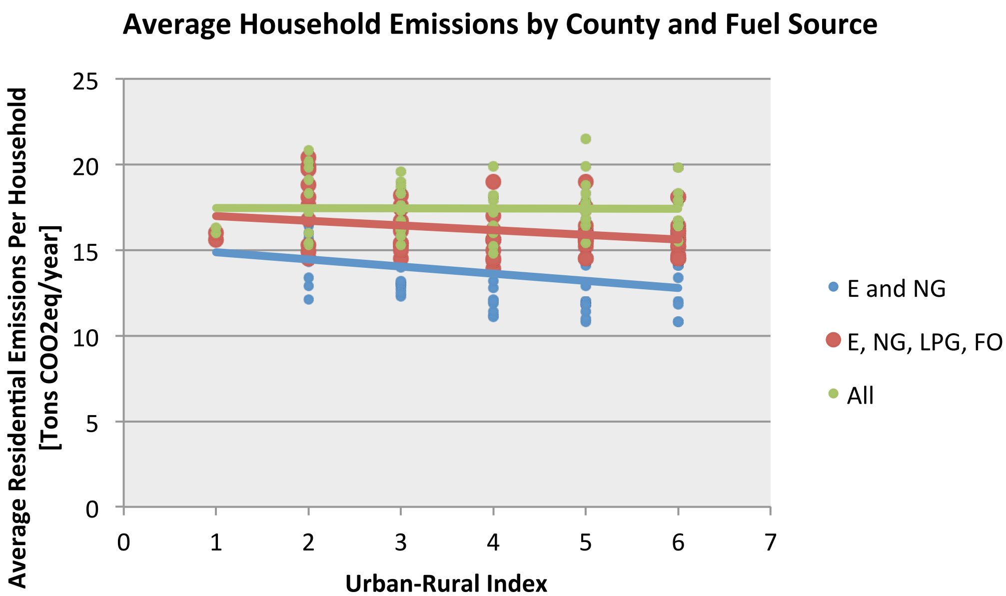


Figure 3-4 Average Household GHG emissions by county including different groups of residential fuels. Blue includes average household emissions for electricity and natural gas. Red includes electricity, natural gas, LPG and fuel oil while green adds coal.

Figure 3-4 shows average household emissions by county and urban-rural index for different groups of residential fuels. The blue line shows average household emissions from electricity and natural gas. Decreasing emissions with increasing ruralism reflects the decreasing use of natural gas and electricity and primary heating fuels. The red and green points add LPG and fuel oil, and coal respectively. The addition of other fuels quickly increases the average emission per household or rural counties, while the total average emissions of the most urban counties only change slightly.

While the majority of residential energy use in the US consists of electricity and natural gas use, other residential fuels become quite significant in rural counties. While this may not be the case in all states, the consideration of other residential fuels in both modeling and planning paradigms is quite important for Pennsylvania, especially in rural counties.

Considering all residential fuels, average emissions per household is relatively flat with increasing urban-rural index. This is the balance of two competing effects: increasing residential energy use and decreasing average income with increasing urban-rural index. Figure 3-5 shows average household emissions plotted against mean county income, colored by rural-urban index. The spread of mean income for rural counties is both narrow and low, while the mean income of urban counties range from very low to very high. Very steep trend lines for rural counties, with an urban – rural index of 5 or 6, show that average emissions per household increase more quickly with income for rural counties than for urban counties.

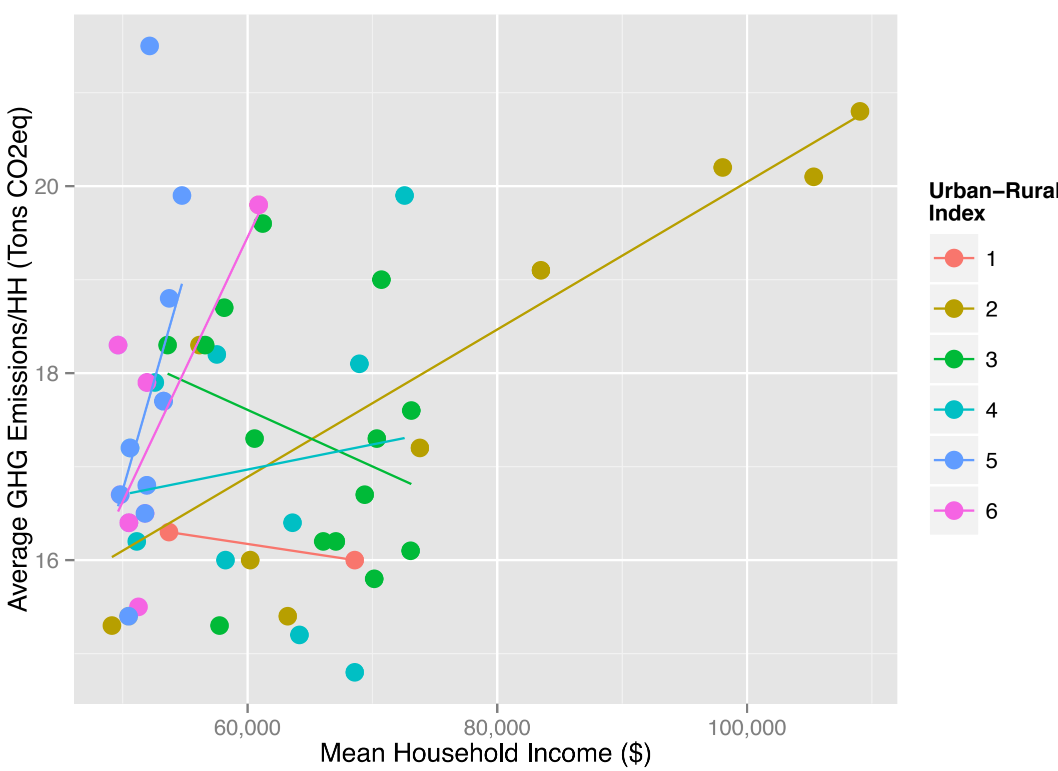


Figure 3-5 Average GHG emissions per household against mean household income for counties in Pennsylvania. Color denotes urban-rural index.

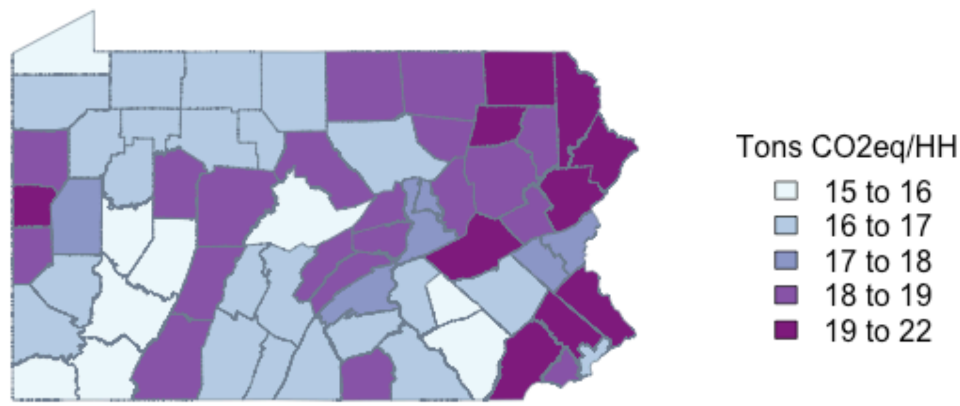


Figure 3-6 Average annual GHG emissions per household in Tons CO_2eq per household.

Figure 3-6 shows the average annual residential emissions per household for counties in PA. The lowest average emissions belong both to rural, low-income counties like Greene and Indiana County and counties with middle average income and middle urban rural index like Erie County. The highest average emissions are found in rural counties in North East Pennsylvania and wealthy suburban counties surrounding Philadelphia.

3.4.2. Household Transportation

Household vehicle use and the associated emissions also vary widely by county in Pennsylvania. As expected, average VMT and annual fuel use is larger in rural counties while average fuel economy of county vehicle fleets decreases with increasing urbanity, shown in Figure 3-7.

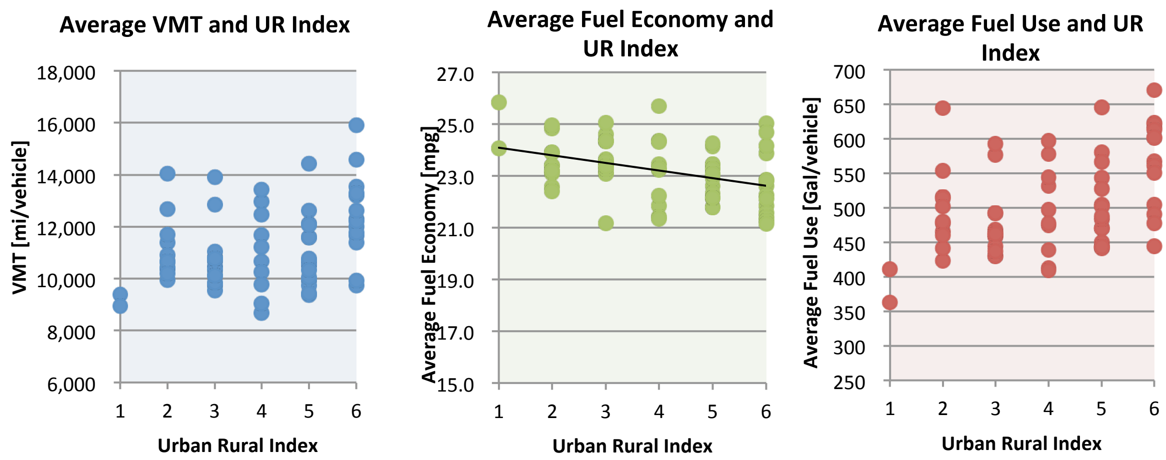


Figure 3-7 Average annual VMT, fuel economy, and fuel use by county plotted against county urban rural index.

Table 3-3 shows the mean and standard deviation of VMT, fuel economy, and annual fuel use per vehicle for select counties. It also shows sample size of estimates derived from safety inspection data, the total vehicle registrations in 2009, and county urban-rural index. Additional summary statistics for VMT, fuel economy, and annual fuel use by county are shown in Appendix B. Figure 3-8 shows the average VMT for counties in Pennsylvania. Average VMT ranges from just under 9,000 mi/vehicle/year in Philadelphia to just under 16,000 mi/vehicle/year in Fulton County. The counties with the highest VMT are rural counties with the exception of Pike County, the only county in Pennsylvania that is part of the New York-Newark-Jersey City metropolitan statistical area. Although highest VMT and fuel use is experienced in rural counties, some rural counties still experience a lower annual VMT of less than 1200 VMT/year.

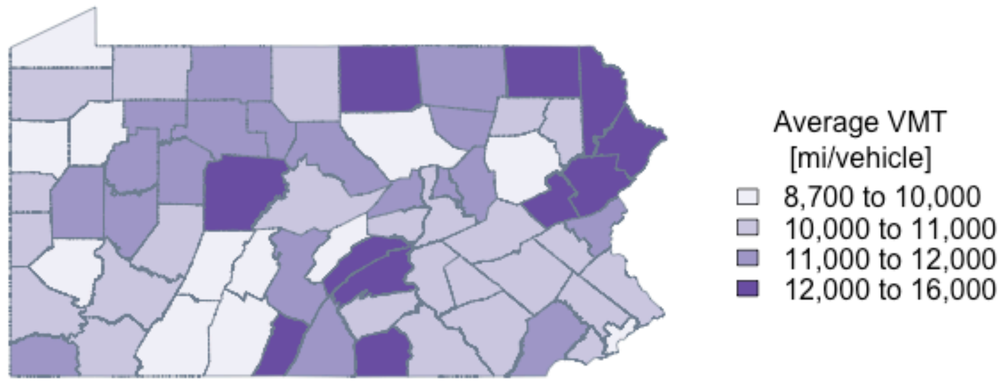


Figure 3-8 Average annual VMT by county.

Table 3-3 Mean and standard deviation of VMT, Fuel Economy, and annual fuel for select counties. Additional summary statistics for all counties are shown in Appendix B.

				VMT [mi/veh]		Fuel Economy [mpg]		FUEL [Gallons]	
Name	**Sample Size**	**Registrations 2009**	**UR Index**	**Mean**	**St Dev**	**Mean**	**St Dev**	**Mean**	**St Dev**
Adams County	5,675	69,283	4	12,947	7,641	25.7	6.9	532	341
Allegheny County	108,955	714,390	1	9,377	6,192	24.1	5.4	411	298
Beaver County	11,896	106,542	2	10,367	6,608	23.2	4.9	466	319
Bedford County	333	33,420	6	9,737	5,856	22.6	5.2	444	283
Centre County	4,510	71,432	4	10,673	6,621	23.4	4.3	475	324
Chester County	53,476	321,336	2	11,694	6,898	23.9	5.8	514	331
Clarion County	236	21,847	6	11,987	6,488	21.8	4.8	567	326
Clearfield County	175	46,492	5	14,435	8,313	23.3	4.6	645	406
Cumberland County	30,905	155,329	3	10,669	6,581	24.4	5.7	459	307
Juniata County	317	14,032	6	14,573	9,076	24.7	7.2	615	394
Lawrence County	5,974	55,112	5	10,691	7,144	24.1	5.7	470	346
Monroe County	8,971	110,637	4	13,419	9,099	23.3	5.9	597	420
Philadelphia County	30,334	579,728	1	8,937	5,868	25.8	5.6	363	258
Pennsylvania	739,047	7,549,729	-	10,401	6,809	24.0	5.6	455	323

3.5. Results

Results in this section reflect the emissions changes from migration flows in 2008. Migration patterns in PA are very similar from 2006-2011; however, the total number of migrating household varies from 114,600 in 2011 to 123,500 in 2008. While the sum of total emissions changes may be slightly larger in 2008 because of high migration rates, the relationship between emission changes in different counties remains constant over the years, shown in Appendix B. From 2006 – 2011, migration patterns in Pennsylvania showed an exodus from urban centers to suburban counties, however this trend reversed in following years. The results shown in this chapter, using 2008 migration data, are very similar to the emissions changes from migration in other years from 2006-2011, but likely different than results from an analysis reflecting migration patterns from 2011-2013.

3.5.1. Residential Energy Emissions

Figure 3-9 shows the changes in residential fuel emissions from migrating household in Pennsylvania in 2008. The color of each county represents the sum of residential energy emissions for all households moving to that county. Purple counties show net decreases in emission while red counties show net increases for the flows of households migrating to that county.

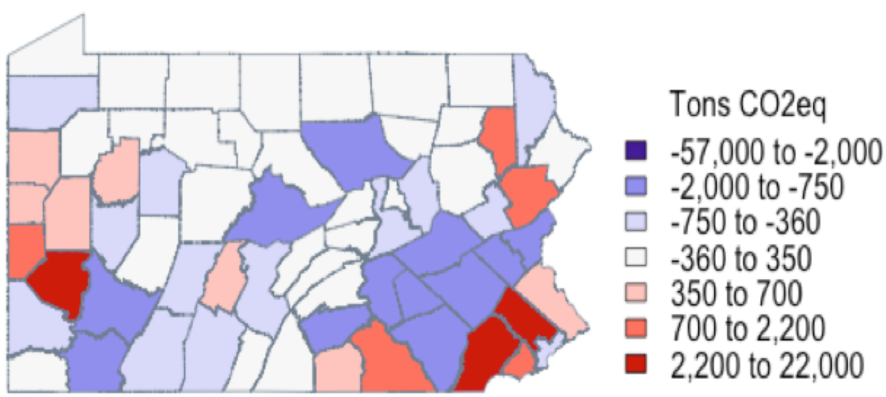


Figure 3-9 Residential emission changes for migrating households in Pennsylvania in 2008 in tons of CO_2eq. Values represent the sum of residential emission changes for all households moving into a county.

The sum of all residential emissions changes for households migrating within Pennsylvania in 2008 is +400 tons CO_2eq. Similar to the state migration analysis in the previous section, total emission sum to near zero values, but it represents the balance of many emissions increases and many emissions decreases.

The two major urban centers in Pennsylvania show different residential emission stories. Philadelphia, is colored light purple while its surrounding suburban counties are largely dark red; this represents households moving to Philadelphia and decreasing their emissions and households moving to suburban counties and increasing their emissions. Allegheny County however, shows the opposite story. Allegheny County is dark red, showing emissions increasing for households moving there, while many of it's suburban counties are light purple, representing net emissions decreases.

3.5.2. Household Transportation Emissions

Figure 3-10 shows the total changes in household transportation emissions for household moving within Pennsylvania in 2008. The sum of all transportation emissions changes from migrating households is +9,000 tons CO_2eq. Similar to residential emissions changes, transportation emissions balance to small net changes under current migration patterns.

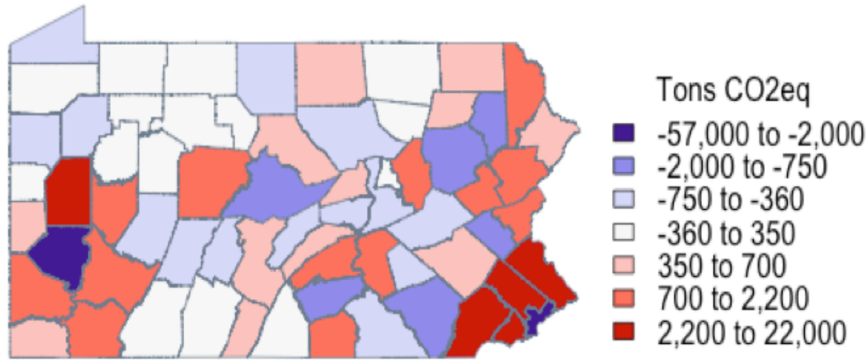
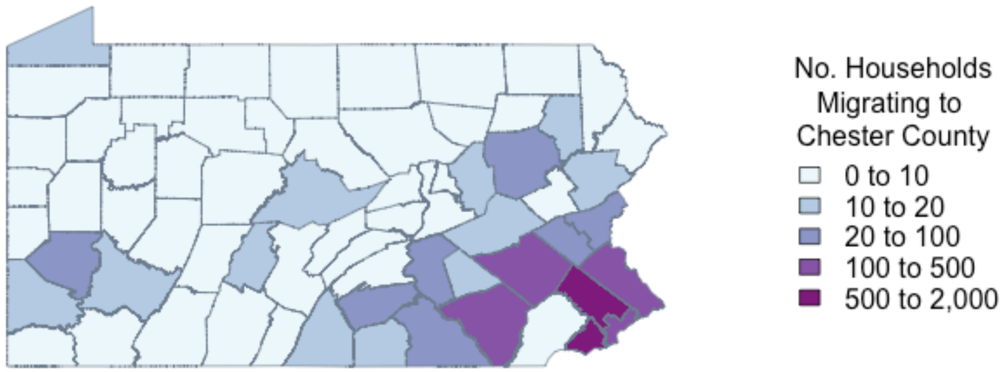


Figure 3-10 Transportation emission changes for migrating households in Pennsylvania in 2008 in tons of CO_2eq. Values represent the sum of transportation emission changes for all households moving into a county.

The emission sums in Figure 3-10 reflect the number of households in flows, where they move from, and the change in emissions they experience. Households moving to the most urban counties experience the largest magnitude of emissions decreases because Allegheny and Philadelphia Counties have the lowest VMT and the highest number of migrants. Even though suburban counties surrounding Allegheny and Philadelphia Counties have low to mid average VMT, households migrating to these counties experience emissions increases because these households primarily migrate mainly from Allegheny and Philadelphia.

Migration flows to two fringe counties, Chester County and Westmorland County are shown in Figure 3-11a and b respectively. They show the number of household moving to those counties from other counties in Pennsylvania. Households primarily move to these counties from their surrounding counties.



a)

b)

Figure 3-11 Migration flows into a) Chester County and b) Westmoreland County from other counties in Pennsylvania in 2008.

3.5.3. Total Household Emissions

Figure 3-12 shows the sum of total household emissions changes (residential emissions and household transportation emissions) from migrating households in 2008. The sum of all total household emissions changes from migrating households is +10,000 tons CO_2eq. Again, this near zero emission sum tells the story of many households experiencing residential and transportation emission increases and many households experiencing decreases.

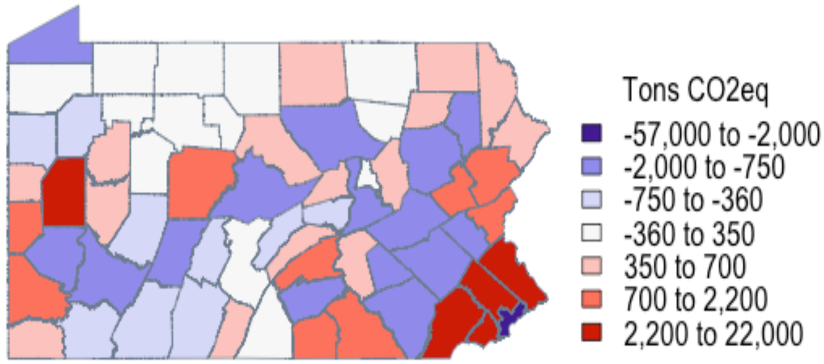


Figure 3-12 Total Household emissions (residential and transportation emissions) changes for migrating household in Pennsylvania in 2004 in tons of CO_2eq. Values represent the sum of emission changes for all households moving into a county.

Unlike the state analysis, shown in Chapter 2, changes in total household emissions at the county level are dominated by transportation emissions. This is unsurprising, because characteristics that effect residential energy use, like climate zone and the electricity grid emissions factors used in this analysis, are more homogenous over a state than VMT, which varies widely with county urbanity. The range of emissions sums vary from -57,000 tons CO_2eq for households moving to Philadelphia, to +22,000 tons CO_2eq for household moving to wealthy suburban counties of Philadelphia. These sums have the largest magnitude because the flows between Philadelphia and its suburban counties are the largest and represent the largest emissions difference per household, also shown in Figure 3-13 and Figure 3-14. The emissions savings from households moving to more energy efficient urban centers is countered by the emissions increases of households moving to suburban outlying counties.

Figure 3-13 and Figure 3-14 show radial diagrams of the emissions flows from households migrating between counties in Pennsylvania. Figure 3-13 shows the migration flows that sum to emissions decreases, while Figure 3-14 shows the migration flows that sum to emissions increases. Counties in Pennsylvania are organized around the circumference of the graph. They are organized and colored by groups of counties. The county groups include Philadelphia County, suburban counties of Philadelphia, outlying counties around Philadelphia, Erie, Rural Middle Pennsylvania, suburban Allegheny County, and Allegheny County. Lines connecting counties represent the emissions changes from migration flows between origin and destination counties and are colored by Origin County. The width of each line represents the sum of emissions changes for all households in that flow. Wider lines represent larger emissions changes (positive or negative).

Figure 3-13, which shows flows summing to emissions decreases, is dominated by households moving from suburban counties to urban centers. No flows in Figure 3-13 originate from Philadelphia County. This means that the sum of emissions changes for all flows from Philadelphia sum to net emissions increases, and are therefore shown in Figure 3-14. Individual households moving from Philadelphia may experience decreases, but total flows from Philadelphia sum to net increases.

The Philadelphia area has a larger population than the Pittsburgh area (Allegheny County); it thus has larger migration flows and dominates the figure; however, the story of households leaving Allegheny county suburban counties for Allegheny County is still apparent. In 2008, urban centers experienced net negative migration, more households moved to Philadelphia and Allegheny County than left. Even so, there are still a significant number of households migrating to Philadelphia and Allegheny County and they represent important emissions decreases to balance the emissions increases shown in Figure 3-14. There are also a number of emissions decreases from households leaving wealthy suburban counties of Philadelphia for the more outlying counties of Philadelphia. Other than these flows, the outlying Philadelphia counties as well as the rural mid Pennsylvania counties mostly consist of household shuffling within these groups and canceling out small emission changes amongst themselves.

Figure 3-14, which shows flows summing to emissions increases, is dominated by households leaving Philadelphia and Allegheny County for their respective suburban counties. The figure also shows moderate emissions increases from household moving from outlying counties to suburban counties. In Allegheny County these emissions increases are dominated by transportation emissions increases, while in Philadelphia they consist of both residential emissions and transportation increases.

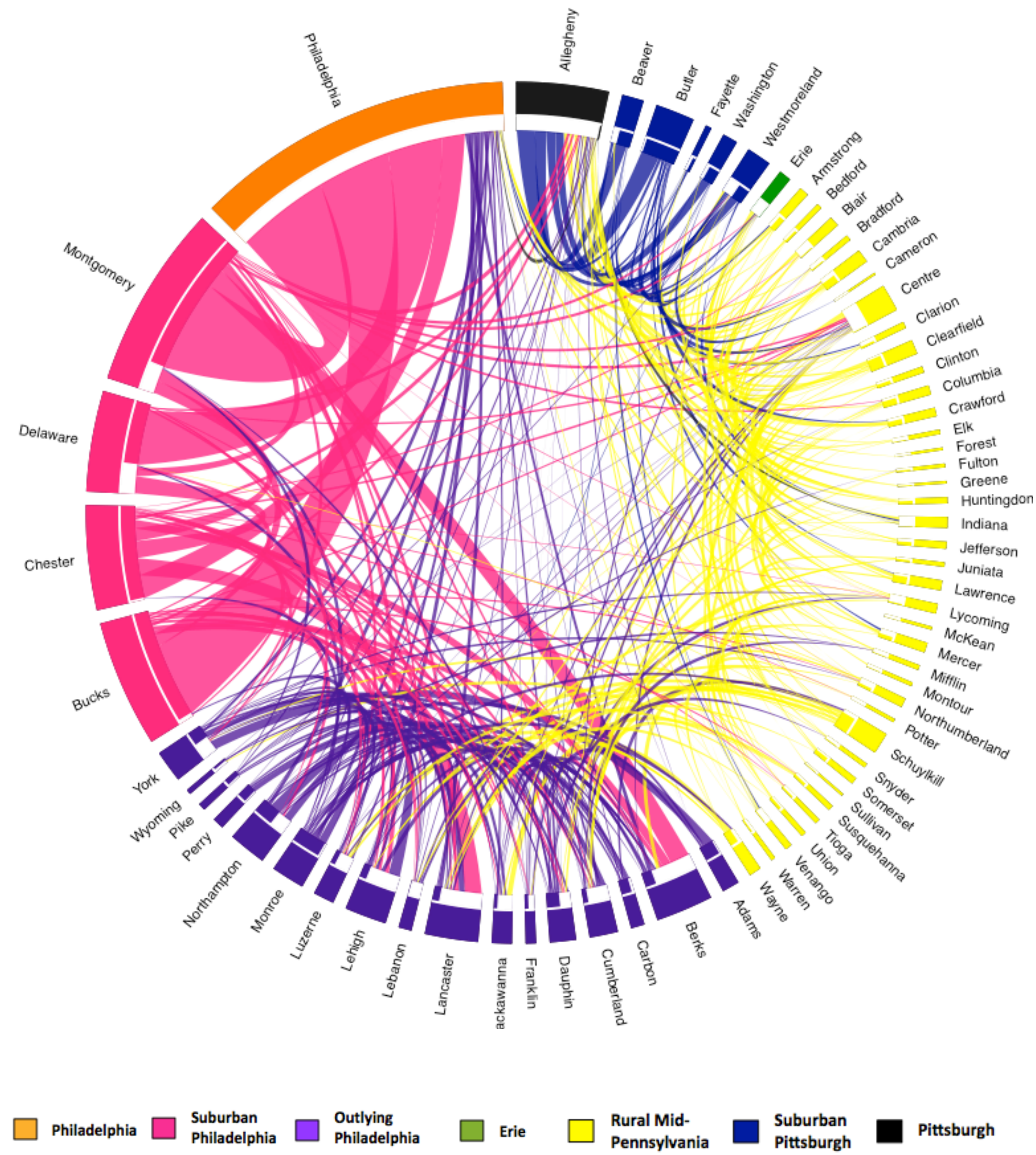


Figure 3-13 Radial migration diagram showing the net emissions changes for county migration flows in Pennsylvania that sum to emissions decreases.

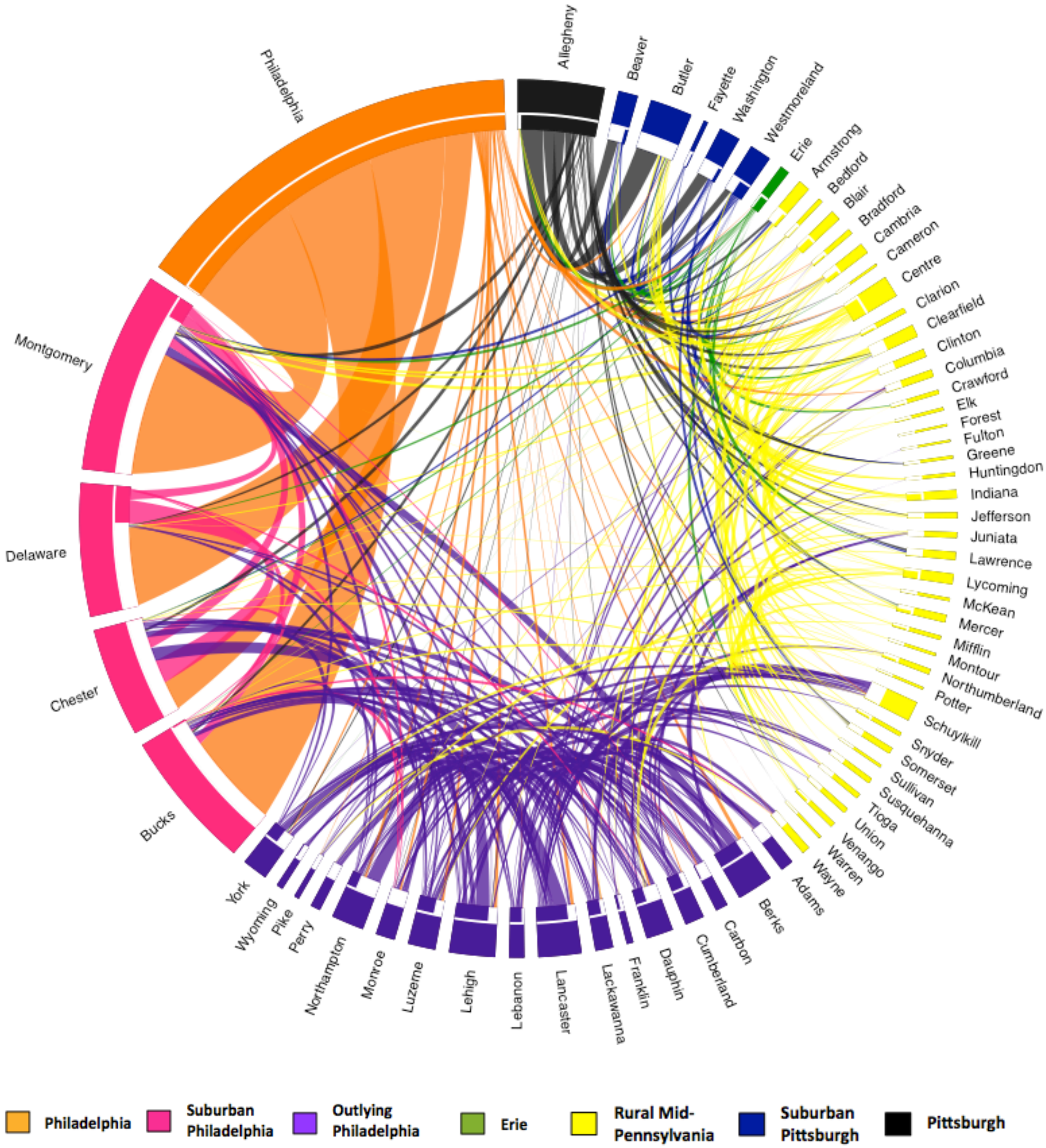


Figure 3-14 Radial migration diagram showing the net emissions changes for county migration flows in Pennsylvania that sum to emissions increases.

3.6. Uncertainty

3.6.1. Estimating Heating Fuel Use and Residential Energy Emissions

Because of the format of ACS data, with "Other fuels" expenditure lumped into a single observations, the wide variation in primary heating fuel use over Pennsylvania increases the uncertainty associated with predicting household emissions.

Estimating emissions from other fuel expenditure is more uncertain than estimating emissions from natural gas or electricity. Estimating emissions for very rural counties is more uncertain than for very urban counties, because a higher percent of household energy expenditure is categorized as "other fuels'. LPG and fuel oil likely dominate other fuels expenditure. For households that report LPG, fuel oil, or coal as the primary heating fuel, we assume that other fuels expenditure is only spent on the primary heating fuel. Households reporting coal as primary heating fuel likely also purchase LPG or fuel; however, there is not enough data in ACS or RECS to support estimates of how much.

Other fuels expenditure in ACS likely includes expenditure on wood, however many households that use wood do not purchase wood. RECS data does not include data on wood expenditure. If many households were reporting wood expenditure in ACS data, while wood expenditure is excluded from RECS, we would expect the distribution of ACS other fuel expenditure to be shifted right compared to RECS data; however, this is not the case, shown in Figure 3-15b.

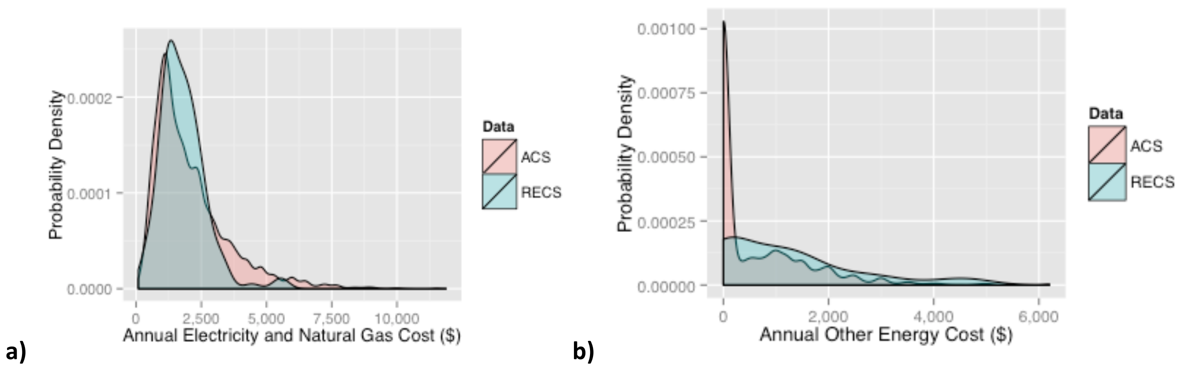


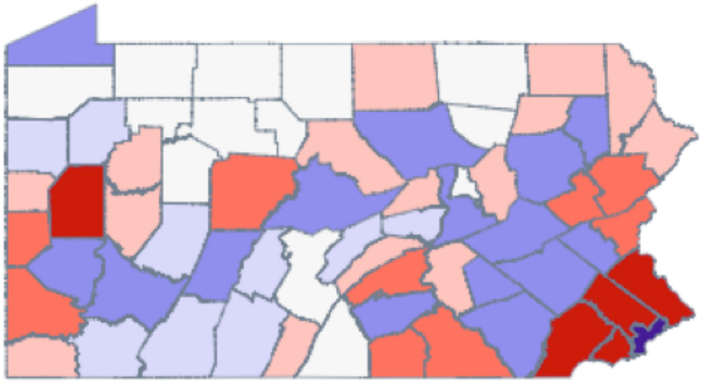
Figure 3-15 Comparison of distributions of annual energy expenditure in rural Pennsylvania by Data Set for a) electricity and natural gas and b) other fuels.

RECS microdata was consulted to estimate average wood use for households in the north east using wood as a primary heating fuel, however of the 2200 households sampled by recs from the North East census region, only 9 households report wood as a primary heating fuel. Due to the lack of data, wood is excluded from this analysis. This likely underestimates the emissions of households in rural Pennsylvania that use wood as a primary, or secondary, heating source. Emissions estimates of household that use wood as a primary heating source are the most uncertain estimates.

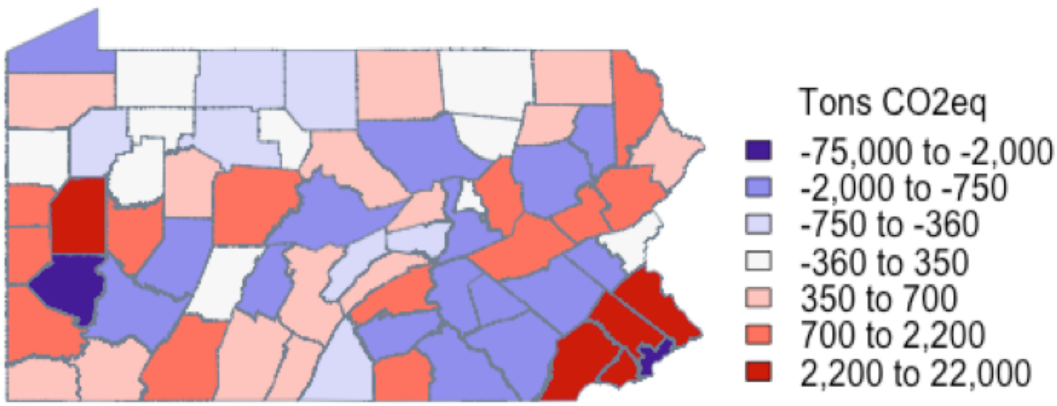
3.6.2. BTU versus Income Method

Described in the methods section, two methods were used to establish the relationship between the residential energy use of a household in its origin and destination county. The results section shows the BTU method, where we assume that the energy use of a household in its origin and destination state is correlated based on percentile of total energy use, measured in BTUs. This section compares the BTU method with the Income method.

The methods estimate similar results for most counties, however the results of a few counties are drastically different, shown in Figure 3-16 and Table 3-4.



a)



b)

Figure 3-16 Comparison of county emissions sums using the a) income method and b) BTU method. Colors represent the sum of emissions for all households migrating into each county.

The difference between estimates for Allegheny and Philadelphia represent 50% of the total difference for the entire state. The other 5 counties in the table represent an additional 20%. The difference between the methods for Allegheny County and Philadelphia are so large for 2 reasons. First, those two counties have the most migrants, 8600 households and 11500 households in 2008 respectively. Second, those counties also have wider income and energy use distributions. Many of the migrants to those counties come from lower income origin counties, so the income method predicts a smaller energy use (because those households have smaller income) than the BTU method. The income method estimates large net negative (or less positive) emission sums for 7 of the 8 counties shown in the table however it does not consistently predict more negative sums for all 67 counties in Pennsylvania.

Table 3-4 Residential county emission sum estimates by the BTU method and the Income method. Estimates are the sum of emission changes for all households moving to a county. Full table shown in Appendix B.

	BTU	Income
Allegheny County	8,400	-11,500
Cumberland County	-1,600	-7400
Philadelphia County	-400	-17,800
Schuylkill County	-2,600	6,400
Lancaster County	-5,500	-9,000
Chester County	8,500	2,200
Montgomery County	10,500	1,100
York County	2,500	-4,000
Pennsylvania	280	-72,400

The income method estimates a net negative change in emissions from migrating households, -72,000 tons CO_2eq, while the BTU method estimates +400 tons CO_2eq.

While the two methods conflict over the emissions fate of households moving to urban counties, they agree about the surrounding fringe counties of both urban centers in PA. Households that move to counties surrounding Allegheny County experience a decrease in residential emissions while households moving to surrounding counties of Philadelphia experience emissions increases.

It is unclear which method is more appropriate but the opposite net emissions sum from the two methods illustrate how fragile the emissions balance of migrating household is.

3.7. Forecasting

This analysis showed the emissions implications of migration within Pennsylvania from 2006-2011. Between those years, Pennsylvania saw migration to suburban counties from both urban centers and more outlying counties. From 2006-2011, counties with a UR Index of 1, 4 and 5 (the most urban and moderately rural) experience net negative migration while counties with a UR Index of 2 and 3, suburban counties, saw net positive migration. While suburban counties saw net positive migration, many households still moved away from suburban counties to urban centers. The competing emissions changes from these migration patters resulted in a net balance; however, these migration trends may not continue. From 2010-2013, US urban centers, on average experienced higher growth rates than suburban counties, primarily due to migration. This re-urbanization may contribute to net emissions decreases in the future as more households leave rural and suburban counties for more efficient urban centers.

The growth of shale gas production in north eastern and southwestern Pennsylvania will certainty affect growth in Pennsylvania and may affect migration trends of household moving within the state. Shale production is located in rural counties in southwestern and northeast Pennsylvania. Form 2007 – 2012, these counties, including Lycoming and Bradford Counties in the north east and Indiana and Allegheny counties, saw employment growth in the oil and gas industries(Jones and Kammen 2014; Cruz 2014). These counties have some of the highest average carbon emission per household from both residential energy and transportation. It is possible that growth in these rural counties along with net negative migration to large urban centers, will shift the current zero balance of emissions changes and Pennsylvania will see increasing carbon emissions from household mobility.

3.8. Discussion

From 2006 – 2010, the emissions changes experiences by households moving between counties in Pennsylvania have balanced to small net numbers. The emissions increases from households moving to metropolitan fringe and suburban counties are countered by the emissions decreases from the many households moving to low emission urban centers, even though urban centers experienced net negative migration. This is another confirmation that suburbanization negates the effects of urbanization and the move to more efficient cities.(The United States Conference of Mayors 2011; Jones and Kammen 2014)

This net zero balance is a somewhat precarious balance that although neutral now, may not be balanced in the future. The growth of shale gas production in rural counties with high average VMT and residential energy emissions may increase net household emissions in Pennsylvania. Migration to and growth in these areas will also produce emissions from end uses and sectors not modeled in this analysis. Beyond the obvious increase in industrial activity and emissions, the energy use and emissions of goods and services is likely significant in these areas.

This analysis also highlights the importance of other residential fuels besides electricity and natural gas. Because residential energy in the US comes primarily from natural gas and electricity, the most GHG mitigation strategies in the residential end use energy sector are focused on reducing the use of these fuels. However the residential energy use of many rural counties relies heavily on residential fuels other than electricity and natural gas. Rural communities in Pennsylvania will have to apply different mitigation strategies to achieve residential GHG reductions.

This analysis showed that, in Pennsylvania, the relationship between urbanity and average residential energy emissions is roughly flat. Given the similarities in residential energy emissions, emissions changes of migrating household are dominated by transportation emissions, which often increase in both fringe metropolitan counties and rural counties.

4. Historical Carbon Footprinting and Implications for Sustainability Planning: a Case study of the Pittsburgh Region

4.1. Introduction

With recent IPCC reports calling for greenhouse gas (GHG) emissions reductions of 80% by 2050, climate change and emissions goals have become a large policy motivator, especially at the local level. To date, mayors of more than 1000 US cities have agreed to meet or exceed Kyoto Protocol targets (7% reduction from 1990 levels by 2012) by joining the US Conference of Mayors' Climate Protection Agreement(Covenant of Mayors 2011; The United States Conference of Mayors 2011). More than 3000 European cities have agreed to meet or exceed the European Union 20% CO_2 reduction objective by 2020 by joining the Covenant of Mayors(ICLEI 2010; Covenant of Mayors 2011).

Cities are conducting regular GHG inventories to inform emission reduction planning and to monitor progress. Many cities follow GHG inventory protocols developed by the International Council for Local Environmental Initiatives (ICLEI) (WBCSDWRI 2004; ICLEI 2010) or schemes derived from those and other protocols such as the World Resources Institute and World Business Council for Sustainable Development's GHG protocol for corporate accounting and reporting (ICLEI 2010; WBCSDWRI 2004). These protocols call for, at minimum, identifying Scope 1 emissions (direct emissions from burning fuel and process emissions) and Scope 2 emissions (indirect emissions from electricity and steam, aka, IEAP) (Ramaswami et al. 2008; ICLEI 2010; WBCSDWRI 2004). However, some proposed inventory methods are beginning to include scope 3 (other indirect emissions) and life cycle emissions (Ramaswami et al. 2008; Hillman and Ramaswami 2010; Kennedy et al. 2010). Recent research on local GHG inventories has focused on developing consistent, general methods for city footprinting (Blackhurst et al. 2011; Ramaswami et al. 2008; Hillman and Ramaswami 2010; Kennedy et al. 2010). Blackhurst (Blackhurst et al. 2011) suggests inventory techniques that can improve baseline assessment, progress monitoring, and Climate Action Plan (CAP) design.

To plan emission reductions, many cities and states have developed Climate Action Plans (CAPs). CAPs generally list and discuss specific interventions or strategies intended to reduce emissions, such as retrofitting buildings, converting to green roofs, and reducing the use of private automobiles. Existing CAPs have a wide range of emission reduction goals. For example, the City of Portland targets 80% emissions reduction below 1990 levels by 2050 (City of Portland and Multnomah County 2009) while Philadelphia targeted 10% reduction from 1990 levels by 2010 (ICLEI USA 2011; City of Philadelphia 2007). A sample of 102 CAPs (ICLEI USA 2011) show that about 20% of cities have a reduction target of 80% or higher and about 60% of cities have reduction targets of 30% of lower, with the remaining 20% in the middle. However, cities with more aggressive reduction targets seem to allow themselves more time to get there, as about 70% of cities have an average reduction schedule of about 1-2% per year, with about 20% being below 1% per year.

Recent studies highlight the magnitude and scope of the activities necessary to achieve stated emission reduction goals (Olabisi et al. 2009; California Council on Science and Technology 2013). For example, Minnesota could require the total decarbonization of electricity and transportation sectors to reach 80% reduction goals (Blackhurst 2011; Olabisi et al. 2009). Blackhurst (Blackhurst 2011) estimates that Pittsburgh could achieve its goal of 20% reduction over 20 years by spending about $1M-$8M per year on residential and commercial efficiency measures.

This study considers the implications of long-term, historical energy and GHG emissions trends for planning future emissions reductions.

While long-term, historical GHG emission records are available at the national level for some countries like Sweden (Tol, Pacala, and Socolow 2009; Lindmark 2002) and the US (US Energy Information Administration 2011c; Tol, Pacala, and Socolow 2009) to our knowledge, such records are not are available at the local scale. The local scale is important when considering GHG emission reductions given that most GHG reduction planning to date has occurred locally and that local authorities significantly influence GHG emissions through infrastructure provisions, energy provisions, and land use planning. Thus, national trends may obscure factors influencing GHG emissions (as this study demonstrates) and may not properly reflect the mechanics necessary to achieve significant GHG reductions given the role of state and local factors.

The Pittsburgh region, presents a useful case study due to its history of significant socio-economic changes and their subsequent influence on energy use and GHG emissions. The City of Pittsburgh makes up 25% of Allegheny County's population and 13% of its land area. After growing as the steel production powerhouse of the United States through the mid 1900's**,** Allegheny County experienced a significant decline of the heavy industry, jobs, and population throughout the 1970s and 1980s when the steel industry fell. For example, population peaked in the 1970s at 1.6 million and is currently around 1.2 million. The number of employees in the primary metals industry peaked at 89,000 in the 1940's and is about 8,800 as of 2000. With the loss of heavy industries, Allegheny County's economic structure transitioned to education, healthcare, and high technology.

4.2. Methodology

This study presents an inventory of the total energy use and CO_2 emissions in Allegheny County for each decadal year from 1900 – 2000. Energy use and CO_2 emissions were estimated for four end use sectors: residential, commercial, industrial, and transportation.

4.2.1. Energy

For each end use sector, a national or state energy intensity, or collection of energy intensities, was multiplied by an Allegheny County allocation factor to estimate total energy use, shown in Equation 16.

$$E = I \times A$$

Equation 16

Where:

E = total sector energy use;

I = energy intensity per allocation unit, derived from state and national data (i.e. energy per household);

A = allocation factor used to scale local, state, and national consumption indicators to Allegheny County (i.e. number of households in Allegheny County).

A complete table of data sources for intensities and allocating factors for all sectors is shown in Appendix C.

4.2.2. Electricity

The electricity grid mix for Pennsylvania from 1960-2000, obtained from US Energy Information Administration's (US EIA) State Energy Data System (SEDS)(US Energy Information Administration 2011c) is shown in Appendix C. Coal comprised 95% of electricity generation in 1960 and contributed to a smaller percentage of electricity generation as the century progressed. Based on this trend, electricity generated before 1960 in Allegheny County was assumed to be generated

100% by coal. For 1950-2000, electricity system losses for generation, transmission, and distribution were provided in SEDS and energy and CO_2 emissions associated with these losses were included in energy and emission estimates. Electricity system losses prior to 1950 were estimated assuming the ratio of total system losses to total electricity use in 1950 was the equal to that in 1930 and 1940. Electricity used prior to 1930 was reported as negligible(Morrison 1992).

4.2.3. Emissions

CO_2 emissions were calculated from total energy estimates using carbon dioxide emission factors from the EIA Voluntary Reporting of Greenhouse Gases Program (US Energy Information Administration) and corresponding fuel mixes from state and national energy use data. This analysis did not track other GHG emissions such as methane and N_2O in the form of CO_2 equivalents nor process emissions.

Total emissions were calculated using Equation 17 below.

$$Total\ Emissions = \sum E_{fuel} \times F_{fuel}$$

Equation 17

Where:

$E_{fuel} =$ Energy use of a specific fuel within an end use sector;

$F_{fuel} =$ CO_2 emission factor, from EIA or calculated for Electricity, for that fuel source;

Emissions were calculated for the combustion of biomass, petroleum, natural gas, and coal at buildings. Emissions from the combustion of fuels for electricity production are included within the calculated Pennsylvania electricity emission factor.

An electricity CO_2 emission factor (MMt CO_2/ Billion BTU electricity) for each decade was calculated using the PA electricity mix and carbon dioxide emission factors from the Voluntary Reporting of Greenhouse Gases Program (US Energy Information Administration), assuming 100% combustion, for each fuel source used to generate electricity. The electricity grid mix for any given year was assumed to be the same for all four energy use sectors.

4.2.4. Residential Sector

Decadal energy intensities, I, in units of energy per household, were calculated for 1900-1940 using energy values presented by Morrison (Morrison 1992);for 1950 using US EIA's Annual Energy Review (US Energy Information Administration); and for 1960-2000 using Pennsylvania state estimates from SEDS(Morrison 1992; US Energy Information Administration 2011c). The numbers of households were obtained from various Census reports. The decadal energy intensities were multiplied by A, the number of households in Allegheny County, to estimate total energy use.

Each source providing state and national energy use also provided a corresponding fuel mix. Total residential energy consumption was separated into energy use by fuel type using the fuel mixtures given by each source. The fuel sources used included anthracite coal, bituminous coal, natural gas, petroleum, biomass, geothermal, solar, and electricity (including electricity system losses). For 1950 to 2000, EIA SEDS coal category was further broken down into bituminous and anthracite coal using the fuel mixes presented by Morrison (Morrison 1992) for these years. Since Morrison did not list any values after 1990, the proportion of anthracite to bituminous coal in 2000 was assumed to be the same as 1990. Households used very little coal in these decades; therefore, this assumption does not have a large impact on the final values.

4.2.5. Commercial Sector

Decadal energy intensities, I, in units of energy per commercial sector employee from 1960-2000 were calculated using Pennsylvania state energy consumption estimates from EIA SEDS database (US Energy Information Administration 2011c).Commercial energy consumption data for decades before 1960 were unavailable. Thus, energy intensities prior to 1960 were estimated using a linear regression of commercial energy consumption per employee versus year for the 1960-2000 data. Regression results and discussion are shown in Appendix C.

Local commercial sector energy use and CO_2 emissions were estimated using, A, the number of commercial sector employees. For 1960-2000, numbers of commercial sector employees in Allegheny County were reported directly, by county, in the US Census(US Census Bureau 1923; US Census Bureau 1999a; US Census Bureau 1999b; US Census Bureau 2006). Commercial employees for 1900 - 1950 were not consistently reported for Allegheny County and are thus derived from employment data of areas in and around Allegheny County. For example, commercial employment for 1910-1920 was scaled to Allegheny County by population from data for the city of Pittsburgh (US Census Bureau 1923; US Census Bureau 1913).

Similar to the residential estimates, total commercial energy use was separated by fuel to estimate CO_2 emissions. Total energy use estimates were broken down using fuel mixes from SEDS for PA for 1960 – 2000 and the EIA Annual Energy review for 1950. Before 1950, energy values were broken down using the same fuel percentages as the residential sector as reported by Morrison(Tarr 1981; Morrison 1992).

4.2.6. Industrial Sector

Allegheny County's industrial sector energy consumption and CO_2 emissions were estimated by scaling (national and/or state) industrial sector employees available from the US Census Manufactures Area Reports and various other census reports (US Census Bureau 1997; US Census Bureau 1947; US Census Bureau 1910). Similar to the commercial sector, estimating the number of industrial sector employees in Allegheny County often involved manipulation of other local area data; for example, Allegheny County employment data was scaled up from Pittsburgh data by population for 1904 – 1914.

Allegheny County industrial energy estimates include the largest 10 industries by employment and energy value for each decade. Decadal energy intensities, I, for each industry were in units of energy per industry employee. Generally, the dominant industries included primary metals, fabricated metal products, petroleum and coal products, computer and electronic production, and food products. The number of employees in metals and machinery industries was never below 70% of total industrial employment from 1900 to 1970, but dropped to 45% by 2000. While some industries, like metals and machinery industries, remained relevant through most of the planning horizon, the top 10 industries changed each decade. Estimates for decadal years were interpolated if data for a specific decadal year were not available. National energy consumption by industry was available was for 1947-1980 from the U.S. Census of Manufactures (US Census Bureau 1947) and 1991-2002 from EIA Manufacturing Energy Consumption Survey(US Energy Information Administration 1991). Because no data for national fuel consumption by industry was found prior to 1947, 1947 energy intensities were used for all calculations prior to 1947.Therefore, the trend in industrial sector energy use prior to 1950 only reflects the changes in number of industrial employees, not the changing energy intensities of each industry. The world energy efficiency of iron production increased about 20% efficiency from 1920 – 1940. As the primary metals industry was the prominent industry in Allegheny County, estimates for the first half of the century may be low.

The CO_2 emissions inventory was estimated from the energy use inventory and corresponding fuel mix data available from EIA (US Census Bureau 1947; US Energy Information Administration 1991). The fuel mix for industries prior to 1947 was assumed to be entirely coal, as a worst-case scenario, since no data was available. This method only accounts for CO_2 emissions from energy and electricity use. Because of the unavailability of historical data, this method did not include industrial process emissions, for example fugitive emissions from coke or cement manufacturing, which underestimates total industrial CO_2 emissions, perhaps significantly. However, process emission are currently not addressed in local climate planning, and because of their small contribution to total CO_2 emissions today, will likely not play a role in future local climate planning.

4.2.7. Transportation Sector

Between 1900 and 2000, Allegheny County experienced major transportation infrastructure transitions similar to those in other metropolitan regions. At the beginning of the twentieth century, Allegheny County residents rode horses, trolleys, and inclines (funiculars) for transportation. By the end of the century, personal motor vehicles and buses had replaced most of those forms of transportation. Allegheny County has also historically observed freight and waterborne transportation because of its history as an industrial center and location at major inland rivers. This study examined energy use and carbon dioxide emissions associated with burning fuels in highway motor vehicles (cars, diesel powered buses, trucks, etc.), airplanes, trains, and waterborne shipping vessels. Horses, trolleys, and recreational boat use were estimated at less than one percent of annual transportation energy and are not included in the analysis. Similarly, subways, inclines, and highway motor vehicles that used neither gasoline nor diesel were not included.

Energy use from rail transportation was estimated by scaling (state and/or national) miles of operating rail line to Allegheny County. Freight transportation energy intensity, I, in units of total energy per miles of operating line, was calculated using data from U.S. Statistical Abstracts and the Bureau of Transportation Statistics on railroad fuel consumption (Bureau of Transportation Statistics; US Census Bureau) . Data estimating operating rail line miles in Allegheny Country over the century were unavailable; however, historical and current maps showed that the amount of major rail lines laid in the county changed little over the century. Although this excludes the effect of abandoned lines in Allegheny County, operating lines were assumed constant from 1900 to 2000. While A, miles of operating line, was assumed constant, national energy intensity, I, decreased over the century, reflecting the declining importance of rail transportation in the US. However even with this assumption, rail transportation contributes very little to total energy use in Allegheny County at the end of the century.

Railroad fuel mixes for the century were acquired from the National Transportation Statistics by the Bureau of Transportation Statistics (Bureau of Transportation Statistics 2011) and various editions of the U.S. Statistical Abstracts (US Census Bureau). The use of fuels other than coal, diesel, and electricity were negligible. The earliest reported fuel mix for railroads was for 1921 (100% coal) (West 2010). It was assumed that the fuel mix for 1900 – 1920 was the same as 1921.

Energy use from waterborne freight transportation was estimated by scaling (state and/or national) ton-miles of goods to those passing through Allegheny County. National energy intensities per ton-mile, I, for waterborne freight transportation were obtained from Davis *et al.* (Davis, Diegel, and Boundy 2009). The energy intensity for waterborne transport, not accounting for efficiency, stayed constant at 500 BTU/ton-mile, as waterborne transportation efficiency ranged from 420 to 550 BTU/ton-mile from1980 to 2000(Davis, Diegel, and Boundy 2009). A, the ton-miles of goods passing through Allegheny County, was obtained from War Department(US War Department 1922), US Army Corps (Engineers 1965; Engineers 1955; Engineers 2001) and Industrial Data book for Pittsburgh(University of Pittsburgh, 1936). Waterborne transportation used steam engines before 1940, but by 1945 engines were dominated by diesel fuel. There was no data available for energy intensity or energy use for waterborne transportation by steam engine. Efficiency changes for steam engines were assumed to parallel efficiency changes in coal fired power plants over the first half of the century (detailed in the Appendix). It was assumed that steam engines were powered entirely by coal pre 1945 and powered entirely by fuel oil post 1945.

This study's analysis of motor vehicles includes all highway vehicles that run on gasoline, diesel, or gasohol. This includes most buses, the trucking industry, and taxis. It does not include vehicles used primarily off roads or vehicles powered by electricity, methane, or hydrogen. Yearly Pennsylvania state fuel consumption per person was calculated using data available in the Federal Highway Administration report on Highway Statistics (Federal Highway Administration 2009b). Annual fuel consumption data is not available for decades before 1930, fuel consumption per person for 1900 – 1920 was assumed to be the same as 1930. As vehicle ownership was very small in these decades, this assumption does not largely affect final values.

All air traffic in and out of airports in Allegheny County from 1960- 2000 was included in this study. Two airports in the county serve the metropolitan area: Pittsburgh International Airport (formerly Greater Pittsburgh International Airport) and Allegheny County Airport. National energy intensities, I, per person, were calculated using total national aviation energy use from the Transportation Energy Data Book(Davis, Diegel, and Boundy 2009). A, was assumed to be the population of the Pittsburgh-New Castle Pennsylvania Combined Statistical Area (PA CSA), which approximates the area of service of the two airports. All fuel was assumed to be jet fuel. While there are no accepted standards for allocating air emissions, the potential uncertainty introduced by our approach does not significantly influence the overall conclusions given air travels relative share of emissions.

4.3. Results

4.3.1. Residential

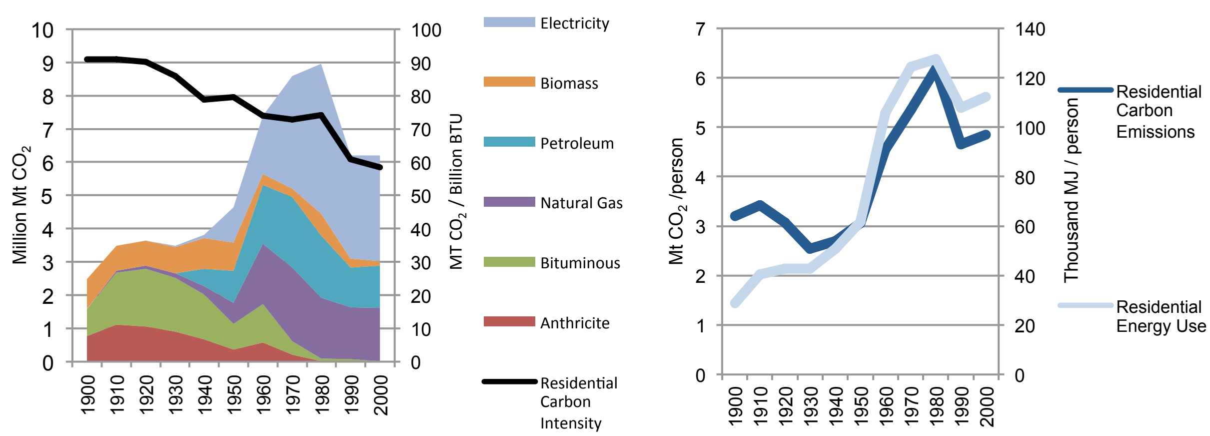


Figure 4-1: Total residential CO_2 emissions estimates (in Million metric tons) from residential energy consumption in Allegheny County, PA from 1900 – 2000, by fuel source shown with residential carbon intensity (Left). Per capita CO_2 emissions and energy use estimates in Allegheny County, PA from 1900 – 2000 (Right).

Figure 4-1 shows estimated total and per capita residential CO_2 emissions for Allegheny County. Underlying energy values are shown in the Appendix C; however, because CO_2 emissions are calculated from burning fuel, they show the similar trends over the century. Total residential CO_2 emissions more than doubled over the course of the 20th century, peaking in 1980 then decreasing, primarily due to significant, rapid electrification and post war consumption of appliances. With widespread electrification around 1930, per capita energy use and CO_2 emissions increased until 1980. Fuel use progressed from being entirely biomass and coal, used for heating and cooking, to being primarily electricity and natural gas with moderate amounts of petroleum usage, for heating, lighting and other amenities. The fuel transitions from 1940-1970 were driven by the needs of new end uses, increased access to natural gas, and awareness of the negative impacts of coal(US Energy Information Administration 2011c; Tarr 1981).

Post-1980, residential carbon dioxide emissions decrease faster than energy consumption (shown in Appendix C) most likely due to a transition to lower carbon fuels and combustion efficiencies, especially in electricity production. Nuclear energy comprised less than 1 % of PA electricity in 1970, but grew to 5% in 1980, and 33% by 1990 by replacing coal(ICLEI USA 2011; US Energy Information Administration 2011c). Although the carbon intensity of the fuel mix steadily declined over the century, decreasing by 1/3 of its original value, total carbon dioxide emissions in 2000 were five times that of 1900 while per capita emissions were three times more than in 1900.

4.3.2. Commercial

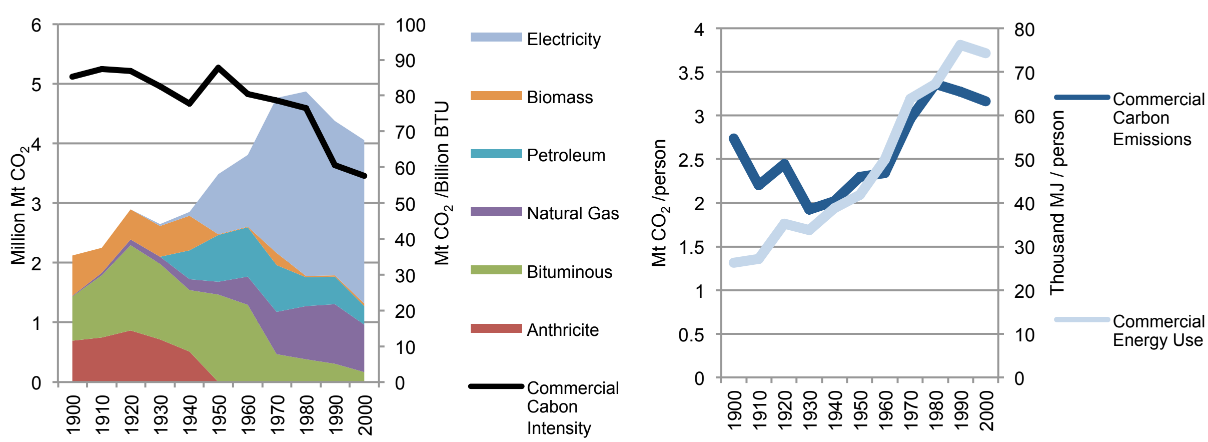


Figure 4-2: Total commercial CO_2 emissions estimates from commercial energy consumption in Allegheny County, PA from 1900 – 2000, by fuel source shown with residential carbon intensity (Left). Per Capita CO_2 emissions and energy use estimates in Allegheny County, PA from 1900 – 2000 (Right).

Figure 4-2 shows that total commercial carbon emissions follow trends similar to the residential sector: significant fuel transitions occurred mid-century and total emissions peaked in 1980. While the population of Allegheny County declined, both total and per capita commercial sector energy consumption, shown in Appendix C, leveled rather than declined correspondingly as the residential sector did. This reflects the observed economic transition away from metal and manufacturing industries to service industries like healthcare. In 1970, at the beginning of the decline of the steel industry, commercial employees made up 20% of the Allegheny population, but 1980, they accounted for 30% of the population.

4.3.3. Industrial

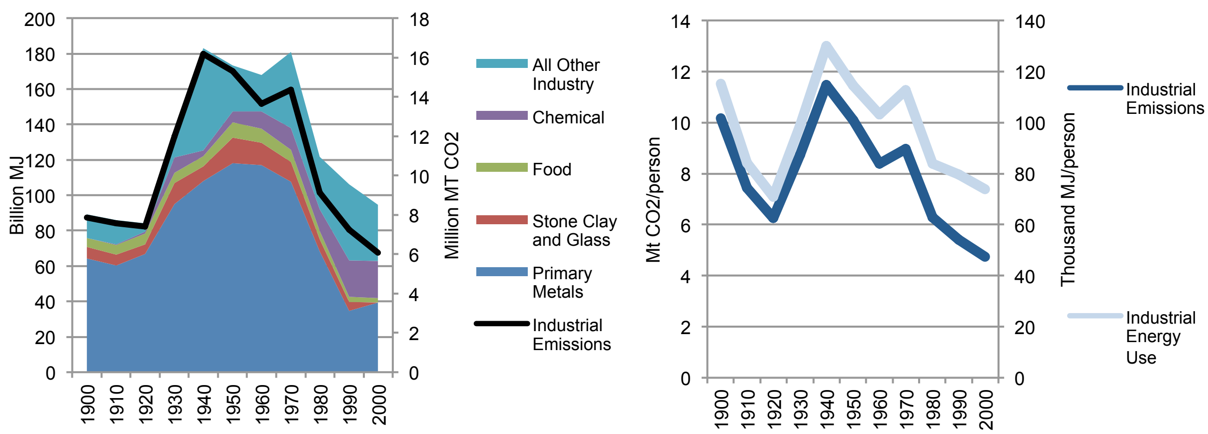
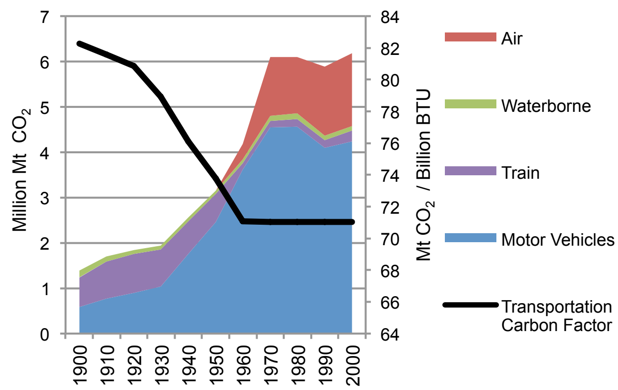


Figure 4-3: Industrial energy use estimates in Allegheny County, PA from 1900 – 2000, by industry shown with total Industrial CO_2 emissions (Left). Per Capita Industrial CO_2 emissions and energy use estimates in Allegheny County, PA from 1900 – 2000 (Right).

Figure 4-3 shows that the changes in the industrial sector are dominated by the rise and fall of the steel industry over the century. The primary metals industry accounted for two thirds of industrial energy use in 1900, peaked mid-century, and then rapidly declined after 1970. The sector nearly doubled in energy use from 1900 to 1950, but dropped below 1900 energy use by 2000. Energy use from most industries not associated with the primary metals stayed relatively consistent, with emissions from the chemical industry and "other industry" category partially increasing after 1970. Total industrial sector energy use in 2000 were about half of their peak value in 1940.

4.3.4. Transportation



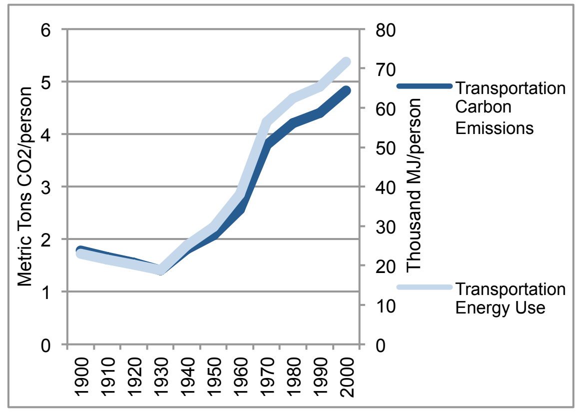
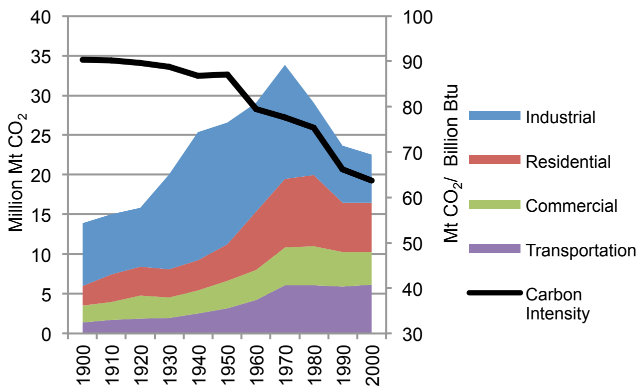


Figure 4-4: Total Transportation emission estimates in Allegheny County, PA from 1900 – 2000, by transportation method (Left). Per Capita Transportation CO_2 emissions and energy use estimates in Allegheny County, PA from 1900 – 2000 (Right).

Figure 4-4 shows the total emissions by the transportation sector in Allegheny County from 1900-2000. Emissions were dominated by train and motor vehicle energy use at the beginning of the century train transportation became less important with time. By 1970 transportation was dominated by air and motor vehicle transportation. While population decreased starting in 1970, transportation emissions leveled, which was coupled with increasing per capita transportation emissions and energy use.

4.3.5. Allegheny County Totals



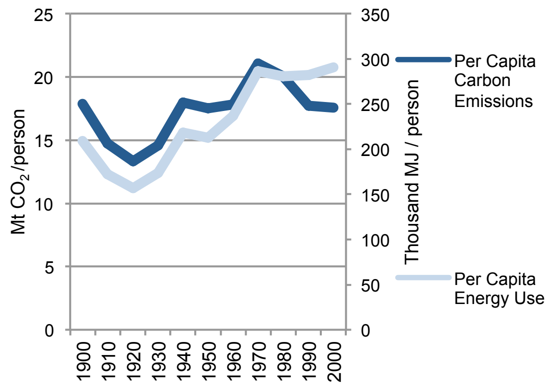


Figure 4-5: Energy consumption and CO_2 emissions estimates in Allegheny County for the first year of each decade between 1900 and 2000.

Figure 4-5 shows the total and per capita historic energy consumption and CO_2 emissions. Total emissions in Allegheny County peaked in 1970 then declined to just below 1940 levels by 2000. While most counties would be expected to continually increase from 1900, consistently with US emission trends, Allegheny County's emissions trends illustrate its unique industrial history. Much of the increase and decrease in energy consumption and emissions over the century follows the rise and fall of the industrial sector and the subsequent population losses within the county. The industrial sector, which at its peak in 1940 consumed more energy than all of the other sectors combined (shown in Appendix C) and contributed to 40% of emissions, accounts for only a quarter of the county's energy use in 2000. Meanwhile per capita emissions from transportation and commercial activity have been increasing throughout the century with total energy use for those sectors leveling off after 1980. Residential emissions peaked in 1980 and have been falling with the county's population.

While both total emission and energy use (shown in Appendix C) fell after 1970, emissions fall faster than energy consumption, which is illustrated by decreasing black line, carbon intensity. This behavior is related to Allegheny County using fuel with lower carbon content and a larger percentage of low carbon sources of energy. From 1970 to 2000, Allegheny County reduced their total CO_2 emissions by one third through the massive decline of an industrial sector dominated by carbon intensive metal manufacturing; the transportation, residential, and commercial sectors did not substantially contribute to emissions reductions.

4.4. Uncertainty

Creating inventory estimates that span a 100-year time period is an exercise inherently laden with uncertainty. Rather than a highly accurate yearly inventory of CO_2 emissions for Allegheny County similar to inventory methods used today, this study presents trend estimates of CO_2 emissions over time that reflects the size, composition, and fuel mixes of Allegheny County. The largest sources of uncertainty arise from gaps in historical data. State data sets are readily available for 1960 – 2000, but comprehensive, consistent data is less available for the first half of the 1900s. Data gaps were filled with assumptions and regressions detailed in the methods section and Appendix C but result in more uncertain inventory estimates for early years than for more recent years. Uncertainty is also associated with scaling from the state and national level. Alternative scaling factors and their effect on energy estimates were explored, shown in Appendix C. As most commercial energy needs arise from heating and lighting, the square footing of commercial building space would be an ideal allocating factor, but we were unable to locate consistent data throughout the century. Value added and the numbers of production workers in the industrial sector were also explored, but they also yielded incomplete data sets. The alternative allocating factors gave energy estimates that were often within 20% of the presented estimates. As this study focuses on trends over 100 years, allocating factors were chosen primarily for their completeness and consistency over time. Based on data quality and magnitude of assumptions used in methodology, we expect that the sectors will have increasing uncertainty from residential, commercial, transportation, to the industrial sector.

Allegheny County emission estimates were compared with emission estimates for Pennsylvania and the US for 1960 – 2000 using energy use from SEDS. Pennsylvania's and the United States' per capita energy values are similar but consistently higher than the Allegheny County values, although typically not more than 20%. This suggests that our estimates and methods are believable and within the same order of magnitude. While SEDS estimates may not be directly comparable to the presented Allegheny Country values because of differences in scope and method, Allegheny County totals can be reliably compared to themselves to analyze energy use and CO_2 emissions trends within the county over the century.

4.5. Discussion

Over 100 cities and counties have committed to reducing greenhouse gas from their communities(US Energy Information Administration 2011c; ICLEI USA 2011). About 80% of these local governments are planning reductions of at least 1% per year, with most of these local governments planning to reach their goals within 20 years.

Allegheny County's historical emissions demonstrate a similar reduction profile: about a 1% reduction per year from 1970-2000. However, Allegheny County's reduction followed the loss of about 25% of its population and 40% of value added in the industrial sector. These trends highlight the scale of change required to achieve currently planned local emissions reductions.

Additional insights can be gained by comparing historical trends for different geographies. The methods outlined in this paper were applied to EIA SEDS(US Energy Information Administration 2011c) and used to examine CO_2 emissions for states from 1960 to 2000, summarized in Appendix C. Pennsylvania, West Virginia, and Michigan follow trends similar to Allegheny County: peaking around 1970 then decreasing or leveling following the loss of heavy industries. West Virginia's industrial emissions decreased by almost half from 1970 to 2000, while the other sectors combined increased by almost 40%. Seven states had declining or leveling per capita CO_2 emissions from 1970 to 2000; Four states have had declining or leveling per capita CO_2 emissions from 1980 to 2000; Eight additional states had declining per capita emission from 1970 – 1990 but have had increasing per capita emissions from 1990 – 2000.

The loss of heavy industry, jobs, and population is somewhat unique to "Rust Belt" regions in the U.S. Many regions are planning reductions against growing demand for energy services. In these cases, emissions stabilization alone seems extremely challenging. Over the last several decades, California and New York spent billions on energy efficiency to stabilize electricity consumption and have achieved reduction in per capita emissions (Williams et al. 2012; Bachrach, Ardema, and Leupp 2003). Even with these investments, it has been suggested that to reach it's reduction goals California would require decarbonized electrification of transportation and other sectors (Williams et al. 2012). These two "stories" highlight divergent means to similar ends: emissions reductions by attrition of energy consuming activities or investment in infrastructure systems that reduce emissions. Both stories characterize the magnitude of change needed to effect CO_2 emissions.

The historical trends also demonstrate significant differences in trends across end-use sectors. From 1970-2000, residential and commercial emissions decreased by 30% and 20%, respectively. Industrial emissions decreased by about 50%. Transportation emissions actually increased from 1970-2000, despite significant population and job losses. From a planning perspective, the technical feasibility, economic feasibility, and planning horizons for climate reduction strategies likely differ substantially by sector (and end-uses within each sector). However, most planning paradigms and decision support resources treat each sector similarly when establishing reduction goals and schedules.

The methods used here are relatively scalable and transferable. State-level data for both energy intensities, E, and allocating factors, A, are readily available for 1960 – 2000(US Energy Information Administration 2011c) collecting data for A prior to 1960 is a more arduous task, requiring the use of proxy data to characterize E and A. Additional historical environmental footprinting could provide new perspectives when planning energy transitions and greenhouse gas reductions.

The implications of the historical trends shown here are generally consistent with other recent studies that question the adequacy of current GHG planning paradigms and the resources committed to achieving climate action goals (Blackhurst et al. 2011). Despite a significant increase in local climate action planning and associated decision-support, the feasibility of success of current plans remains very skeptical; many planning paradigms do not reflect the scale of change needed to achieve meaningful emission reductions. From a historical perspective, effective action planning requires changing persistent trajectories of energy provisions, demands, and infrastructure. Evaluating CAPs given this historical context can contribute to a better understanding of emissions trends and ultimately better climate action planning. Our results further highlight a need for better decision resources that can support realistic, but effective action planning.

5. Summary, Conclusions, and Policy Implications

5.1. Summary

This thesis explored the idea that living and existing in different places has different impacts, specifically household GHG emissions, and the movement of people to and from those places contributes to net changes and flows of emissions in the US both annually and overtime. It began by estimating the emissions changes that households experience as a result of moving to different states (Chapter 2) and to different counties within the same state (Chapter 3). It then estimated the effect of social, demographic, and economic changes within a region over time by estimating the carbon footprint of Allegheny County over 100 years.

Chapter 2 analyzed the emissions implications of inter-state migration in the US by highlighting the population shift south and west to regions with varying climate and fuel mix. Annually, the 3 million households that move to different states in the US experience many emissions increases and decreases that sum to near zero values. The moderate emissions increases experienced by households moving to the South West, South Atlantic, and middle of the country are balanced by significant emissions decreases from households moving primarily to California and the Pacific Northwest.

Chapter 3 examined the similar effects on county-county migration in Pennsylvania, highlighting the urban-rural index of counties. Similar to chapter 2, many households experience emissions increases and many experience emissions decreases, but the sum of emissions change sum to near zero. In Pennsylvania, from 2006 – 2011, the emissions decreases of many households moving to urban centers was countered by many households leaving urban centers and very rural urban counties for suburban, outlying counties. While urban centers experienced net negative migration during this time period, both in Pennsylvania and through out the US, urban counties saw net positive migration from 2010 – 2013.

Chapter 4 analyzed the long-term energy and emissions effects of regional growth and decline by estimating the carbon footprint of the Pittsburgh region over 100 years. From 1970 to 2000, Allegheny County experienced a 30% decrease in total emissions and energy use from peak values, primarily because of a decline in industrial activity (40% decrease in value added) and the loss of a quarter of its population. Allegheny County's history suggests the scale of change needed to achieve local emissions reductions may be significant; given years of major technological, economic, and demographic changes, per capita emissions in 1940 were nearly the same in 2000. Most local governments are planning emissions reductions rates that exceed 1% per year, which deviate significantly from historical trends. Our results suggest additional resources and improved planning paradigms are likely necessary to achieve significant emissions reductions, especially for areas where emissions are still increasing.

5.2. Future Work

5.2.1. Historical Emissions from Migration

Chapters 2 and 3 showed that the from 2005-2010, the emissions changes from migrating household, both across states in the US and within Pennsylvania, were balanced, which resulted in small net emission increases. Studies have shown that from 1960 – 2000, the population shift south and west likely contributed to flattening per capita residential use in the US(US Energy Information Administration 2012a), however no analysis evaluates the effect of that historical shift on emissions. An analysis of the historical effects of migration in the US on residential energy emissions could identify if the emissions balance seen in 2005-2010 is the norm, or a passing trend that may lead to unbalanced emissions increases (or decreases) in the future. This analysis only looked at a 5 year snap shot of migration in the US when emissions changes from migration were balanced, but this may be an unusual occurrence that is not indicative of how future migration patterns may effect household emissions.

5.2.2. Expanding Environmental Metrics and End Use Energy Sectors

This thesis explored how growth, decline and population shifts overtime affect GHG emissions, only one of many environmental impacts affecting long-term sustainability. Living and existing in different regions or cities has impacts that extend beyond both GHG emissions and the residential and household transportation end use energy sectors. GHG emissions are global impact. Within the scope of this analysis and other GHG footprint analyses, emitting 1 ton CO_2 in Florida, for example, has the same effect as emitting 1 ton CO_2 in California. The same is not true for other relevant metrics like water use or particulate matter (PM) emissions. Chapter 2 showed the large emissions benefit of households moving to California and experiencing emissions decreases that balanced the moderate emissions increases of many other destination states. An analysis on how population shifts in the United States effects residential water use would likely produce very different results. Water stresses in the South West are particularly high and the continuation of population shifts away from the North East and other unstressed regions to the regions with the highest stress will only exacerbate the challenges. Future work considering the environmental implications of migration and population shifts in the US should include environmental metrics that affect regions differently. Living and existing also has energy impacts that extend beyond household end use energy sectors. Households moving to states and regions create additional demand for goods and services, which may have different impacts in different regions that contribute to the flow of emissions.

5.2.3. The Contributions of Migration, Immigration, and Natural Growth to Emissions Trends

This thesis considered annual migration within the US and migration to and from a region over time; it was only concerned with the domestic US population shuffling, or population moving to and from places in the US. However, both migration and natural growth rates drive population growth and emissions associated with that growth. The individual contributions of domestic migration, immigration to the US, and natural growth/fertility to emissions trends poses a relevant comparison that will be explored in future work. Additional analysis of the contributions of immigration and natural growth will likely share 2 similar conclusions with migration analysis. First, the emissions contributions and stories over individual states will vary widely. Second, annual contributions may be seem small, but amount to significant emissions contributions overtime.

Annual emissions contributions from migration will be smaller than emissions contributions from natural growth or immigration, because for a US centric emissions view, they represent a change in emission rather than a flat increase. Analysis of the global emissions changes for immigrants however, would also represent changes like those described in this thesis for migration households within the US. In 2010, the US received 95,000 immigrants from Europe, 66,000 immigrants each from China and India, and 139,000 immigrants from Mexico, all of which have different household emissions profiles from regions in the US.

Natural growth in the US is lower than it has been in the recent past. The total US population growth rate in 2013 slowed to .71%, or less than 2.3 million people, which is the slowest growth rate since the 1930's(Toppo and Overberg 2013). However, the growths of individual states vary widely. Utah's growth rate is almost twice that of the national rate, driven by a high birth rate, while North Dakota's growth rate, driven by the growing oil industry, is 4 times that of the national growth rate. States that historically show large growth rates, like Florida, Arizona, and Nevada, have slowed to moderate growth rates about 1.2%. Florida's growth is driven almost solely by migration, as it's births and deaths are almost equal(Toppo and Overberg 2013).

The contribution of immigration to increasing energy use and emissions in the US is a controversial topic, but estimating its magnitude poses a relevant comparison to the emissions contribution of domestic migration in the US. From 2005 – 2012, the number legal immigrants to the US varied between 1 and 1.2 million people(Office of Immigration Statistics 2013). This represents around half the annual growth of the US population. The emissions contributions of natural growth and immigration will depend on the both size of population growth and it's distribution throughout the US. The accumulation of immigrants in US states tends to be similar to the total population trends of states. States with the largest populations have the largest population of new immigrants, such as California, Texas, Florida, and New York, which in 2010 contained more than half of the total foreign born population that entered the US after 2005(US Census Bureau 2012b).

The actually residential energy use of immigrants may be slightly smaller, but not drastically different from the residential energy use of US citizens. Analysis of ACS utility bill data in Florida, shown in Figure 5-1, shows that the distribution of monthly electricity bills for citizen and non-citizens households (based on the citizenship of the primary householders) are quite similar.

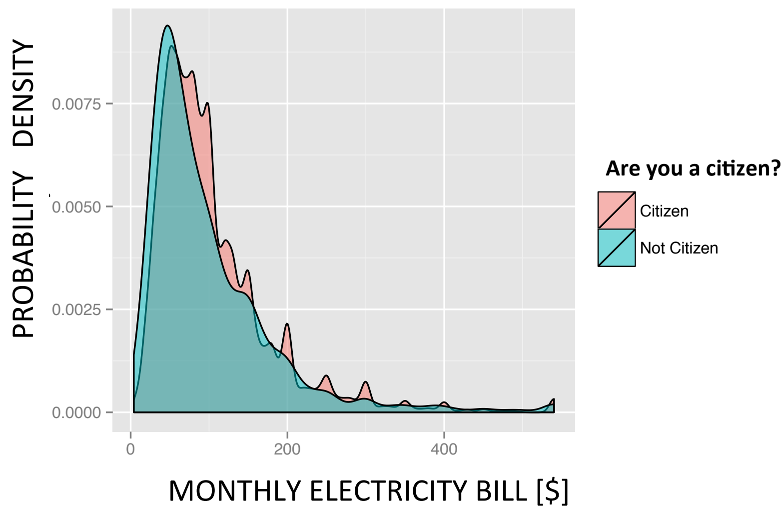


Figure 5-1 Distributions of monthly electricity bills for US citizens and Non US citizens in Florida

Annually, the emissions increases from new immigrants will likely be along the same magnitude as the emissions increases from natural growth, because they represent similar amounts of growth located in the similar states. Emissions contributions of immigrants in the future will not be dominated by annual the emissions of actual foreign-born persons in the US, but of their descendants. A recent US population projection conducted by the Pew Hispanic Center (Passel and Cohn 2008), estimates that immigration after 2008 will account for 82% the population increase in the US by 2050, for baseline projections assuming constant immigration rates. Of that 82%, 57% are foreign-born immigrations and 43% percent represent their descendants.

An analysis estimating the contributions of migration, immigration, and natural growth to emissions trends will likely find the following conclusions:

- Annually the emissions contributions of natural growth and new immigration will likely be similar.

- The US emissions contributions of internal migration will most likely be much smaller than that of natural growth or immigration because they represent a net change, rather than a flat increase in US emissions.
- Overtime immigration will likely contribute to a larger share of emissions because of the natural growth of the immigrant population. The emissions contribution of the descendants of immigrants is just as significant as the emission contributions of immigrants themselves.

5.3. Policy Implications and Final Conclusions

Examining the energy and emissions implications of population shifts at different geographic and time scales can help inform region and metropolitan level planning by showing the regional emissions in the context of the national emissions planning.

US mobility in the past has contributed to changes in energy use and emissions both in specific geographic areas and to changes in US average household energy use over time. Mobility continues to contribute to changing household energy use and emissions for migrating households. Of the households that move every year, almost 60%, move locally within counties and likely don't experience significant emissions changes. Chapters 2 and 3 looked at the emissions implications of migration between states and counties, which together accounts for almost all the remaining 40% of annual moves in the US. Of this 40%, some households experience small emission changes close to zero because they move locally to neighboring states or counties with similar emissions profiles. The close shuffling of these households balance to net zero emissions changes. Many households, however, experience significant emissions increases or decreases as a result of a move. Even though these emissions changes sum to near zero values nationally, these emissions changes represent many household emissions changes.

The total emissions change for the 98,000 households moving to Pennsylvania from other states was approximately -50,000 tons CO_2eq. This is similar to the total emissions changes for the 120,000 households moving within Pennsylvania. This thesis described the emissions implication of two kinds of population shifts, those between regions and between rural and urban counties. The emission effects of these two shifts are similar. Household emissions changes for households migrating between states were dominated by residential energy emissions, while emissions changes for households migrating between counties within Pennsylvania were dominated by transportation emissions. This not surprising because drivers of residential energy emissions, like climate zone and electricity grid mix, vary more over states than within states. This, however, may not be true for smaller less than diverse states than Pennsylvania, where the urbanity of counties varies widely.

Maintaining net emissions form migration both between and within states is a balancing act in the short term. While this balance results in emissions changes that are quite small, Chapter 3 showed that emissions changes from growth and decline over large time spans could be quite significant. Achieving ultimate emissions reductions in communities that expect increasing populations will prove to be quite challenging, and it is questionable that these communities will achieve those goals. Emissions increases within some of these communities may not be necessarily be driving total emissions increase in the US. Growth is usually associated with emissions increases, but when growth is driven by migration from higher carbon regions, low carbon growth can result in net emission decreases, even with population growth.

Planning for low carbon growth is particularly important 2 types of regions or cities:

- **Areas that play an important role in balancing net emissions:** California, pacific north west, and dense urban centers

- **Higher carbon areas that are have or will see high migration rates from low carbon places**: Arizona, Georgia and Texas, and rural counties in PA expecting growth from shale gas production.

High growth rates driven by migration, without low carbon planning for growth could leave to emissions increases rather than the net balances seen in the recent past.

References

Advanced Resource International Inc, IFC International. 2008. *Greenhouse Gas life-Cycle Emissions Study: Fuel Life-Cycle of U.S. Natural Gas Supplies and International LNG*. http://www.adv-res.com/pdf/ari_lca_nov_10_08.pdf.

Bachrach, Devra, Matt Ardema, and Alex Leupp. 2003. *Energy Efficiency Leadership in California: Preventing the Next Crisis*. National Resources Defense Council.

Bento, Antonio M, Maureen L Cropper, Ahmed Mushfiq Mobarak, and Katja Vinha. 2005. "The Effects of Urban Spatial Structure on Travel Demand in the United States." *Review of Economics and Statistics* 87 (3). MIT Press: 466–78.

Bettle, R, C H Pout, and E R Hitchin. 2006. "Interactions Between Electricity-Saving Measures and Carbon Emissions From Power Generation in England and Wales." *Energy Policy* 34 (18): 3434–46. doi:10.1016/j.enpol.2005.07.014.

Bhat, Chandra R, and Sudeshna Sen. 2006. "Household Vehicle Type Holdings and Usage: an Application of the Multiple Discrete-Continuous Extreme Value (MDCEV) Model." *Transportation Research Part B: Methodological* 40 (1): 35–53. doi:10.1016/j.trb.2005.01.003.

Blackhurst, Michael. 2011. "Achieving Realistic Energy and Greenhouse Gas Emission Reductions in U.S. Cities." Pittsburgh: Carnegie Mellon University.

Blackhurst, Michael, H Scott Matthews, Aurora L Sharrard, Chris T Hendrickson, and Inês Lima Azevedo. 2011. "Preparing US Community Greenhouse Gas Inventories for Climate Action Plans." *Environmental Research Letters* 6 (3): 034003. doi:10.1088/1748-9326/6/3/034003.

Brown, Marilyn A, Frank Southworth, and Andrea Sarzynski. 2009. "The Geography of Metropolitan Carbon Footprints." *Policy and Society* 27 (4): 285–304. doi:10.1016/j.polsoc.2009.01.001.

Brownstone, David, and Thomas F Golob. 2009. "The Impact of Residential Density on Vehicle Usage and Energy Consumption." *Journal of Urban Economics* 65 (1). Elsevier Inc.: 91–98. doi:10.1016/j.jue.2008.09.002.

Bureau of Transportation Statistics. 2011. *National Transportation Statistics 2010*. US Department of Transportation.

Bureau of Transportation Statistics. *National Transportation Atlas Database*. Washington DC: US Department of Transportation.

California Council on Science and Technology. 2013. *California's Energy Future: the View to 2050*. California Council on Science and Technology. http://www.ccst.us/publications/2011/2011energy.pdf.

Center for Climate and Energy Solutions. 2014. "Renewable and Alternative Energy Portfolio Standards." *Center for Climate and Energy Solutions*. Accessed September 22. http://www.c2es.org/node/9340.

Chao, Liu, and Shen Qing. 2011. "Computers, Environment and Urban Systems." *Computers, Environment and Urban Systems* 35 (5). Elsevier Ltd: 347–57. doi:10.1016/j.compenvurbsys.2011.05.006.

Chertow, Marian R. 2000. "The IPAT Equation and Its Variants." *Journal of Industrial Ecology* 4 (4). Wiley Online Library: 13–29.

City of Philadelphia. 2007. *City of Philadelphia Local Action Plan for Climate Change*. Philadelphia: City of Philadelphia. http://www.phila.gov/green/PDFs/Attachment1_Philadelphia_Local_Action_Plan_Climate_Change.pdf.

City of Portland, Multnomah County. 2009. "City of Portland and Multnomah County Climate Action Plan." *City of Portland and Multnomah County*, October. Portland, 1–70. https://www.portlandoregon.gov/bps/article/268612.

Claxton, John. 1984. "Any Data or None at All?." *Environment and Behavior* 16 (4): 503–26.

Covenant of Mayors. 2011. "Covenant of Mayors - Signatories." Accessed September 2.

http://www.eumayors.eu/about/signatories_en.html.
Crossett, Kristen M, Thomas J Culliton, Peter C Wiley, and Timothy R Goodspeed. 2004. *Population Trends Along the Coastal United States: 1980-2008*. National Oceanic and Atmospheric Administration.
Cruz, Jennifer. 2014. "The Marcellus Shale Gas Boom in Pennsylvania: Employment and Wage Trends." *Bureau of Labor Statistics*. http://www.bls.gov/opub/mlr/2014/article/the-marcellus-shale-gas-boom-in-pennsylvania.htm.
Davis, S C, S W Diegel, and R Boundy. 2009. *Transportation Energy Data Book*. Vol. 28. Oak Ridge: Oak Ridge National Laboratory.
Deru, M, and P Torcellini. 2006. *Source Energy and Emission Factors for Energy Use in Buildings*. Golden, Colorodo: National Renewable Energy Laboratory. http://www.nrel.gov/docs/fy07osti/38617.pdf.
Dhakal, Shobhakar, and Ram M Shrestha. 2010. "Article in Press." *Energy Policy* 38 (9). Elsevier: 4753–55. doi:10.1016/j.enpol.2009.12.001.
Dietz, Thomas, and Eugene A Rosa. 1997. "Effects of Population and Affluence on CO_2 Emissions." *Proceedings of the National Academy of Sciences* 94 (1). National Acad Sciences: 175–79.
Doucette, Reed T, and Malcolm D McCulloch. 2011. "Energy Policy." *Energy Policy* 39 (2). Elsevier: 803–11. doi:10.1016/j.enpol.2010.10.054.
Engineers, Army Corp of. 1955. *Department of the Army Corps of Engineers Waterborne Commerce of the United States*. Alexandria, VA: US Army Corp of Engineers.
Engineers, Army Corp of. 1965. *Department of the Army Corps of Engineers Waterborne Commerce of the United States*. Alexandria, VA: US Army Corp of Engineers.
Engineers, Army Corp of. 2001. *Department of the Army Corps of Engineers Waterborne Commerce of the United States*. Alexandria, VA: US Army Corp of Engineers.
Ewing, Reid, and Fang Rong. 2008. "The Impact of Urban Form on US Residential Energy Use." *Housing Policy Debate* 19 (1). Taylor & Francis: 1–30.
Federal Highway Administration. 2005. *Table VM-2: Annual Vehicle Miles by Functional System*. US Department of Transportation. https://www.fhwa.dot.gov/policy/ohim/hs05/pdf/vm2m.pdf.
Federal Highway Administration. 2009a. *The National Household Transportation Survey*. US Department of Transportation. http://nhts.ornl.gov/index.shtml.
Federal Highway Administration. 2009b. *Federal Highway Administration Highway Statistics 2008*. Washington, DC: US Department of Transportation.
Federal Highway Administration. 2010. "Highway Statistics Series User's Guide." *Federal Highway Administrations Office of Highway Policy Information*. http://www.fhwa.dot.gov/policyinformation/statistics/2010/userguide.cfm.
Federal Highway Administration. 2011. *Table VM-2: Annual Vehicle-Miles by Functional System*. *US Department of Transportation Federal Highway Administration*. US Department of Transportation. http://www.fhwa.dot.gov/policyinformation/statistics/2010/vm2.cfm.
Glaeser, Edward L, and Matthew E Kahn. 2010. "The Greeness of Cities: Carbon Dioxide Emissions and Urban Development." *Journal of Urban Economics* 67 (3). Elsevier Inc.: 404–18. doi:10.1016/j.jue.2009.11.006.
Gross, Emily. 2006. *Internal Revenue Service Area-to-Area Migration Data: Strengths, Limitations, and Current Trends*. IRS.
Gross, Emily. 2012. *US Population Migration Data: Strengths and Limitations*.
Hawkes, A D. 2010. "Energy Policy." *Energy Policy* 38 (10). Elsevier: 5977–87. doi:10.1016/j.enpol.2010.05.053.
Hillman, Tim, and Anu Ramaswami. 2010. "Greenhouse Gas Emission Footprints and Energy Use Benchmarks for Eight U.S. Cities." *Environmental Science & Technology* 44 (6): 1902–10. doi:10.1021/es9024194.

Hoesly, Rachel, Mike Blackhurst, H Scott Matthews, Jeffrey F Miller, Amy Maples, Matthew Pettit, Catherine Izard, and Paul Fischbeck. 2012. "Historical Carbon Footprinting and Implications for Sustainability Planning: a Case Study of the Pittsburgh Region." *Environmental Science & Technology* 46 (8): 4283–90. doi:10.1021/es203943q.

ICLEI. 2010. "International Local Government GHG Emissions Analysis Protocol (IEAP)," October. ICLEI Local Governments for Sustainability, 1–56. http://carbonn.org/fileadmin/user_upload/carbonn/Standards/IEAP_October2010_color.pdf.

ICLEI USA. 2011. *Empowering Sustainable Communities: ICLEI USA 2010 Annual Report*. ICLEI Local Governments for Sustainability.

ICLEI USA. 2013. "ICLEI USA Members." *Icleiusa.org*. Accessed December 4. http://www.icleiusa.org/about-iclei/members.

Ihrke, David K, Carol S Faber, and William K Koerber. 2011. *Geographical Mobility: 2008 to 2009*.

Ingram DD, Franco SJ. 2014. "2013 NCHS Urban–Rural Classification Scheme for Counties" Vital Health Stat 2 (166). Washington DC: National Center for Health Statistics. http://www.cdc.gov/nchs/data/series/sr_02/sr02_166.pdf.

Internal Revenue Service Statistics of Income Division. "Internal Revenue Service Area-to-Area Migration Data ." Internal Revenue Service. http://www.irs.gov/uac/SOI-Tax-Stats-State-to-State-Migration-Database-Files.

Jones, Christopher, and Daniel M Kammen. 2014. "Spatial Distribution of U.S. Household Carbon Footprints Reveals Suburbanization Undermines Greenhouse Gas Benefits of Urban Population Density." *Environmental Science & Technology* 48 (2): 895–902. doi:10.1021/es4034364.

Kennedy, Christopher, Julia Steinberger, Barrie Gasson, Yvonne Hansen, Timothy Hillman, Miroslav Havránek, Diane Pataki, Aumnad Phdungsilp, Anu Ramaswami, and Gara Villalba Mendez. 2010. "Article in Press." *Energy Policy* 38 (9). Elsevier: 4828–37. doi:10.1016/j.enpol.2009.08.050.

Lee, Sungwon, and Bumsoo Lee. 2014. "Energy Policy." *Energy Policy* 68 (C). Elsevier: 534–49. doi:10.1016/j.enpol.2014.01.024.

Lima Azevedo, Inês, M Granger Morgan, Karen Palmer, and Lester B Lave. 2013. "Reducing U.S. Residential Energy Use and CO_2 Emissions: How Much, How Soon, and at What Cost?." *Environmental Science & Technology* 47 (6): 2502–11. doi:10.1021/es303688k.

Lindmark, Magnus. 2002. "An EKC-Pattern in Historical Perspective: Carbon Dioxide Emissions, Technology, Fuel Prices and Growth in Sweden 1870–1997." *Ecological Economics* 42 (1). Elsevier: 333–47.

Marriott, Joe, and H Scott Matthews. 2005. "Environmental Effects of Interstate Power Trading on Electricity Consumption Mixes." *Environmental Science & Technology* 39 (22): 8584–90. doi:10.1021/es0506859.

Michael Sivak. 2009. "Energy-Demand Consequences of the Recent Geographical Shift in the Metropolitan Population of the US." *Cities* 26 (6). Elsevier Ltd: 359–62. doi:10.1016/j.cities.2009.08.001.

Min, Jihoon, Zeke Hausfather, and Qi Feng Lin. 2010. "A High-Resolution Statistical Model of Residential Energy End Use Characteristics for the United States." *Journal of Industrial Ecology* 14 (5): 791–807. doi:10.1111/j.1530-9290.2010.00279.x.

Molloy, Raven, Christopher L Smith, and Abigail Wozniak. 2011. "Internal Migration in the United States." *Journal of Economic Perspectives* 25 (3): 173–96. doi:10.1257/jep.25.3.173.

Morrison, Bonnie Maas. 1992. "Ninety Years of US Household Energy History: a Quantitative Update." *American Council for an Energy-Efficient Economy (ACEEE)*, 10.125–109.134.

National Renewable Energy Laboratory. 2012. "US Life Cycle Inventory Database." National Renewable Energy Laboratory. https://www.lcacommons.gov/nrel/search.

Office of Immigration Statistics, Department of Homeland Security. 2013. *Yearbook of Immigration*

Statistics: 2012. Washington, DC: US Department of Homeland Security. http://www.dhs.gov/sites/default/files/publications/ois_yb_2012.pdf.

Olabisi, Laura Schmitt, Peter B Reich, Kris A Johnson, Anne R Kapuscinski, Sangwon Suh, and Elizabeth J Wilson. 2009. "Reducing Greenhouse Gas Emissions for Climate Stabilization: Framing Regional Options." *Environmental Science & Technology* 43 (6): 1696–1703. doi:10.1021/es801171a.

Passel, Jeffrey, and D'Vera Cohn. 2008. *U.S. Population Projections: 2005–2050*. Washinton, DC: Pew Research Center. http://www.pewhispanic.org/2008/02/11/us-population-projections-2005-2050/.

Payne, Christopher T. 2000. *Utility Bill Comprehension in the Commercial and Industrial Sector: Results of Field Research*. Lawrence Berkeley National Laboratory. http://escholarship.org/uc/item/5gx362qx.

Pennsylvania Department of Transportations. 2009. *Report of Registrations*. http://www.dmv.state.pa.us/pdotforms/stats/ReportofRegistration2009.pdf.

Puentes, Robert, and Adie Tomer. 2008. "The Road… Less Traveled: an Analysis of Vehicle Miles Traveled Trends in the US."

Quayle, Robert G, and Henry F Diaz. 1980. "Heating Degree Day Data Applied to Residential Heating Energy Consumption." *Journal of Applied Meteorology* 19 (3): 241–46.

Ramaswami, Anu, Tim Hillman, Bruce Janson, Mark Reiner, and Gregg Thomas. 2008. "A Demand-Centered, Hybrid Life-Cycle Methodology for City-Scale Greenhouse Gas Inventories." *Environmental Science & Technology* 42 (17): 6455–61. doi:10.1021/es702992q.

Samson, Jason, Dominique Berteaux, Brian J McGill, and Murray M Humphries. 2012. "Demographic Amplification of Climate Change Experienced by the Contiguous United States Population During the 20th Century." Edited by David Nogues-Bravo. *PLoS ONE* 7 (10): e45683. doi:10.1371/journal.pone.0045683.s008.

Siler-Evans, Kyle, Inês Lima Azevedo, and M Granger Morgan. 2012. "Marginal Emissions Factors for the U.S. Electricity System." *Environmental Science & Technology* 46 (9): 4742–48. doi:10.1021/es300145v.

Sovacool, Benjamin K, and Marilyn A Brown. 2010. "Article in Press." *Energy Policy* 38 (9). Elsevier: 4856–69. doi:10.1016/j.enpol.2009.10.001.

Tarr, Joel A. 1981. "Changing Fuel Use Behavior: the Pittsburgh Smoke Control Movement, 1940–1950." *Technological Forecasting and Social Change* 20 (4). Elsevier: 331–46.

The United States Conference of Mayors. 2011. "The Agreement - Mayors Climate Protection Center." *Usmayors.org*. Accessed September 11. http://www.usmayors.org/climateprotection/agreement.htm.

Tol, Richard S J, Stephen W Pacala, and Robert H Socolow. 2009. "Understanding Long-Term Energy Use and Carbon Dioxide Emissions in the USA." *Journal of Policy Modeling* 31 (3): 425–45. doi:10.1016/j.jpolmod.2008.12.002.

Toppo, Greg, and Paul Overberg. 2013. "U.S. Population Growth Slows to Just 0.71%." *USATODAY.com*. http://www.usatoday.com/story/news/nation/2013/12/30/census-state-population-estimates-growth/4248089/.

Toppo, Greg, and Paul Overberg. 2014. "See Ya, Suburbs: More Want to Live in the Big City." *USATODAY.com*. http://www.usatoday.com/story/news/nation/2014/03/27/census-cities-metro-growth-population/6863219/.

Transportation Research Board. *Driving and the Built Environment*. 298. National Research Council.

University of Pittsburgh. 1936. *Pittsburgh University Industrial Databook for the Pittsburgh District*. Pittsburgh, PA: Bureau of Business Research.

US Census Bureau. 2009. *A Compass for Understanding and Using American Community Survey Data: What PUMS Data Users Need to Know*. Washington DC: US Government Printing Office.

US Census Bureau. 1910. *US Census of Manufactures: 1910 General Summary*. Washington, DC: Government Printing Office.
US Census Bureau. 1913. *US Census of Population 1910*. Vol. 4. US Government Printing Office.
US Census Bureau. 1923. *US Census of Population 1920*. Vol. 4. Washington, DC: US Government Printing Office.
US Census Bureau. 1947. *US Census of Manufactures: 1947 Energy Consumption*. Washington, DC: Government Printing Office.
US Census Bureau. 1997. *US Census of Manufactures: 1997 Area Reports*. Washington, DC: Government Printing Office.
US Census Bureau. 1999a. *US Census CD 1980*. East Brunswick, NJ: GeoLytics.
US Census Bureau. 1999b. *US Census CD 1970*. East Brunswick, NJ: GeoLytics.
US Census Bureau. 2005. *Geographical Mobility Between 2004 and 2005*. US Census Bureau. http://www.census.gov/population/pop-profile/dynamic/Mobility.pdf.
US Census Bureau. 2006. *US Census CD 2000 Long Form*. East Brunswick, NJ: GeoLytics.
US Census Bureau. 2011. "Population Distribution and Change:2000 to 2010." *US Census Bureau*, March, 1–12.
US Census Bureau. 2012a. *County-to-County Migration Flows: 2007-2011 ACS*. US Census Bureau.
US Census Bureau. 2012b. *The Foreign-Born Population in the United States: 2010*. Washinton, DC: US Census Bureau. http://www.census.gov/prod/2012pubs/acs-19.pdf.
US Census Bureau. 2014. "USA QuickFacts." *Quickfacts.Census.Gov*. http://quickfacts.census.gov/qfd/states/00000.html.
US Census Bureau. "2009 American Community Survey1-Year Public Use Microdata Sample." US Census Bureau. http://www2.census.gov/acs2009_1yr/pums/.
US Census Bureau. *US Statistical Abstracts*. 1910, 1921, 1930, 1942, 1952, 1962, 1973, 1984. Washington DC: US Census Bureau.
US DOT Bureau of Transportation Statistics. *Table 4-23: Average Fuel Efficiency of U.S. Light Duty Vehicle*. US Department of Transportation. http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_04_23.html.
US Energy Information Administration. 1991. *US Manufacturing Energy Consumption Survey: 1991*. Washington, DC: US Government Printing Office.
US Energy Information Administration. 2002a. "Voluntary Reporting of Greenhouse Gases Program." *Eia.Gov*. http://www.eia.gov/oiaf/1605/ee-factors.html.
US Energy Information Administration. 2002b. *Updated State-Level Greenhouse Gas Emission Coefficients for Electricity Generation 1998-2000*. US Energy Information Administration. http://www.eia.gov/survey/form/eia_1605/pdf/EFactors1998-2000.pdf.
US Energy Information Administration. 2008. *Annual Energy Outlook 2008*. DOE/EIA-0383(2008). Washington DC: US Department of Energy.
US Energy Information Administration. 2010. *Quarterly Coal Report: October - December 2009*. Washington DC: US Department of Energy. http://www.eia.gov/coal/production/quarterly/archive/0121094q.pdf.
US Energy Information Administration. 2011a. *Annual Energy Outlook 2011*. DOE/EIA-0383(2011). Washington DC: US Department of Energy.
US Energy Information Administration. 2011b. "Carbon Dioxide Emissions Grow in the Residential Sector." *Eia.Gov*. http://www.eia.gov/todayinenergy/detail.cfm?id=1970.
US Energy Information Administration. 2012a. "Population Shifts Across U.S. Regions Affect Overall Heating and Cooling Needs." *Eia.Gov*. EIA. http://www.eia.gov/todayinenergy/detail.cfm?id=8810.
US Energy Information Administration. 2012b. *CE1.1 Summary Totals and Intensities, U.S. Homes*.

2009 Residential Energy Consumption Survey. Washington DC: US Department of Energy. http://www.eia.gov/consumption/residential/data/2009/c&e/summary/xls/CE1.1%20Summary%20Site.xlsx.
US Energy Information Administration. 2013a. “2009 RECS Public Use Microdata.” US Department of Energy. http://www.eia.gov/consumption/residential/data/2009/csv/recs2009_public.csv.
US Energy Information Administration. 2013b. “Heating and Cooling No Longer Majority of U.S. Home Energy Use.” *Eia.Gov*. http://www.eia.gov/todayinenergy/detail.cfm?id=10271&src=%E2%80%B9%20Consumption%20%20%20%20%20%20Residential%20Energy%20Consumption%20Survey%20(RECS)-b1.
US Energy Information Administration. 2013c. *Household Energy Use in Florida*. Washington DC: US Department of Energy. http://www.eia.gov/consumption/residential/reports/2009/state_briefs/pdf/fl.pdf.
US Energy Information Administration. 2013d. *Household Energy Use in Colorado*. Washington DC: US Department of Energy. http://www.eia.gov/consumption/residential/reports/2009/state_briefs/pdf/co.pdf.
US Energy Information Administration. *Voluntary Reporting of Greenhouse Gases Program Fuel Carbon Dioxide Emission Coefficients*. US Department of Energy. http://www.eia.gov/oiaf/1605/coefficients.html.
US Energy Information Administration. 2011c. “State Energy Data System (SEDS): 1960-2012.” *State Profiles and Energy Estimates*. US Department of Energy. http://www.eia.gov/state/seds/seds-data-complete.cfm?sid=US.
US Energy Information Administration. *Total Energy - Annual Energy Review*. US Department of Energy. http://www.eia.gov/totalenergy/data/annual/index.cfm.
US Environmental Protection Agency. 2013. “State and Local Climate and Energy Program.” *US Environmental Protection Agency*. Accessed December 4. http://www.epa.gov/statelocalclimate/state/state-examples/action-plans.html.
US EPA. 2014. *eGRID 9th Edition Version 1.0 Year 2010 Summary Tables*. http://www.epa.gov/cleanenergy/documents/egridzips/eGRID_9th_edition_V1-0_year_2010_Summary_Tables.pdf.
US War Department. 1922. *War Department - US Army Report of the Chief of Engineers*. Vol. 2. Washington, DC: Government Printing Office.
USDA Economic Research Service. 2013. “Population & Migration Overview.” *United States Department of Agriculture Economic Research Service*. http://www.ers.usda.gov/topics/rural-economy-population/population-migration.aspx#.UzIs317TaiQ.
Venkatesh, Aranya, Paulina Jaramillo, W Michael Griffin, and H Scott Matthews. 2011. “Uncertainty in Life Cycle Greenhouse Gas Emissions From United States Natural Gas End-Uses and Its Effects on Policy.” *Environmental Science & Technology* 45 (19): 8182–89. doi:10.1021/es200930h.
WBCSD, WRI. 2004. “The Greenhouse Gas Protocol: a Corporate Accounting and Protocol Standard,” March. The World Business Council for Sustainable Development, 1–116. http://www.ghgprotocol.org/files/ghgp/public/ghg-protocol-revised.pdf.
Weber, Christopher L, Paulina Jaramillo, Joe Marriott, and Constantine Samaras. 2010. “Life Cycle Assessment and Grid Electricity: What Do We Know and What Can We Know?.” *Environmental Science & Technology* 44 (6): 1895–1901. doi:10.1021/es9017909.
Wei, Taoyuan. 2011. “Ecological Economics.” *Ecological Economics* 72 (C). Elsevier B.V.: 70–74. doi:10.1016/j.ecolecon.2011.10.015.
West, D. 2010. “Pennsylvania Railroad Stations Past and Present: Station Database.” Accessed April 24. http://www.west2k.com/pastations/pastations.htm.

Williams, J H, A DeBenedictis, R Ghanadan, A Mahone, J Moore, W R Morrow, S Price, and M S Torn. 2012. "The Technology Path to Deep Greenhouse Gas Emissions Cuts by 2050: the Pivotal Role of Electricity." *Science* 335 (6064): 53–59. doi:10.1126/science.1208365.
York, Richard, Eugene A Rosa, and Thomas Dietz. 2003. "STIRPAT, IPAT and ImPACT: Analytic Tools for Unpacking the Driving Forces of Environmental Impacts." *Ecological Economics* 46 (3): 351–65. doi:10.1016/S0921-8009(03)00188-5.

APPENDIX A. ENERGY AND EMISSIONS FROM STATE-STATE MIGRATION

Table A-1 Average Electricity Emission Factors (lbs CO_2eq/kWh) by state and region from EIA's Voluntary Reporting of Greenhouse Gases Program(US Energy Information Administration 2002a)

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 A-2 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
New Jersey	0.6	0.1	1.2	0.7	0.0	1.4	-5.3	-6.0	-4.5	6.7	5.8	7.8	54,500	1,810	108,000

	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**

Table A-3 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

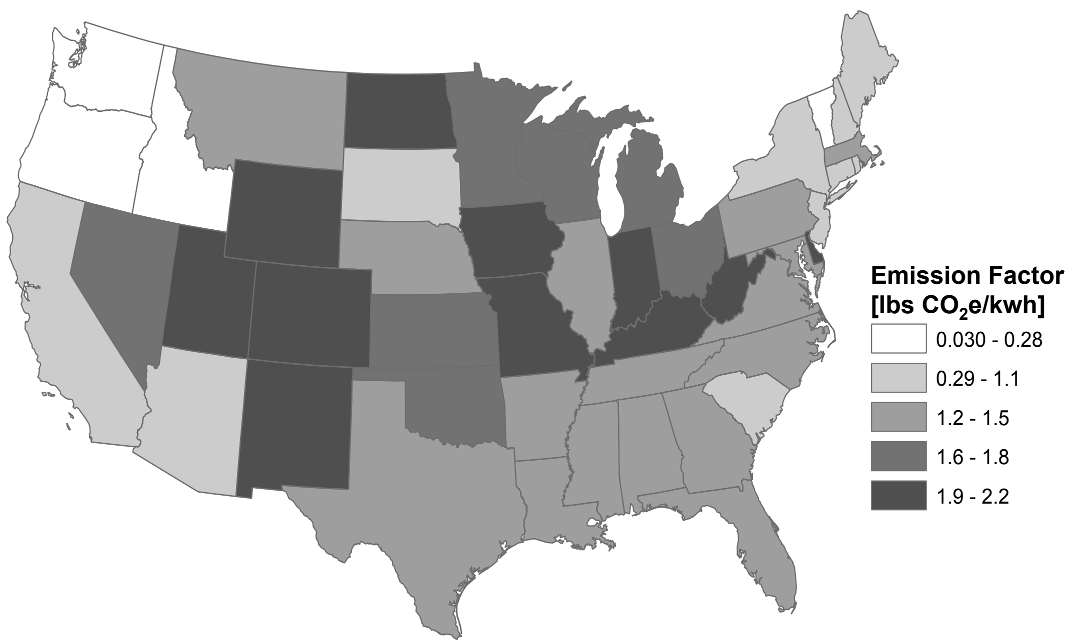


Figure A-1 State electricity emission factors estimated by EIA's Voluntary Reporting Green house Gasses Program(US Energy Information Administration 2002a)

Table A-4 Life Cycle Natural Gas Emission Factors

Source	Emission Factor
Venkatesh et al(Advanced Resource International IncIFC International 2008; Venkatesh et al. 2011)	66 g CO_2eq/MJ $\times\frac{lb\ CO2eq}{453.59g}\times\frac{1055.87MJ}{MMBTU}$ = 153 lb CO_2eq/MMBtu
Advanced resources international(National Renewable Energy Laboratory, 2012; Advanced Resource International IncIFC International 2008)	145 lb CO_2eq/MMBtu
NREL US Lifecycle Inventory Database(National Renewable Energy Laboratory, 2012)	148 lb CO_2eq/MMBtu
Average Emission Factor	149 lb CO_2eq/MMBtu

Table A-5 Other Residential Fuel Emission Factors from NREL Lifecycle Inventory Database(National Renewable Energy Laboratory, 2012)

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

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 A-6.

Table A-6 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

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 A-2 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.

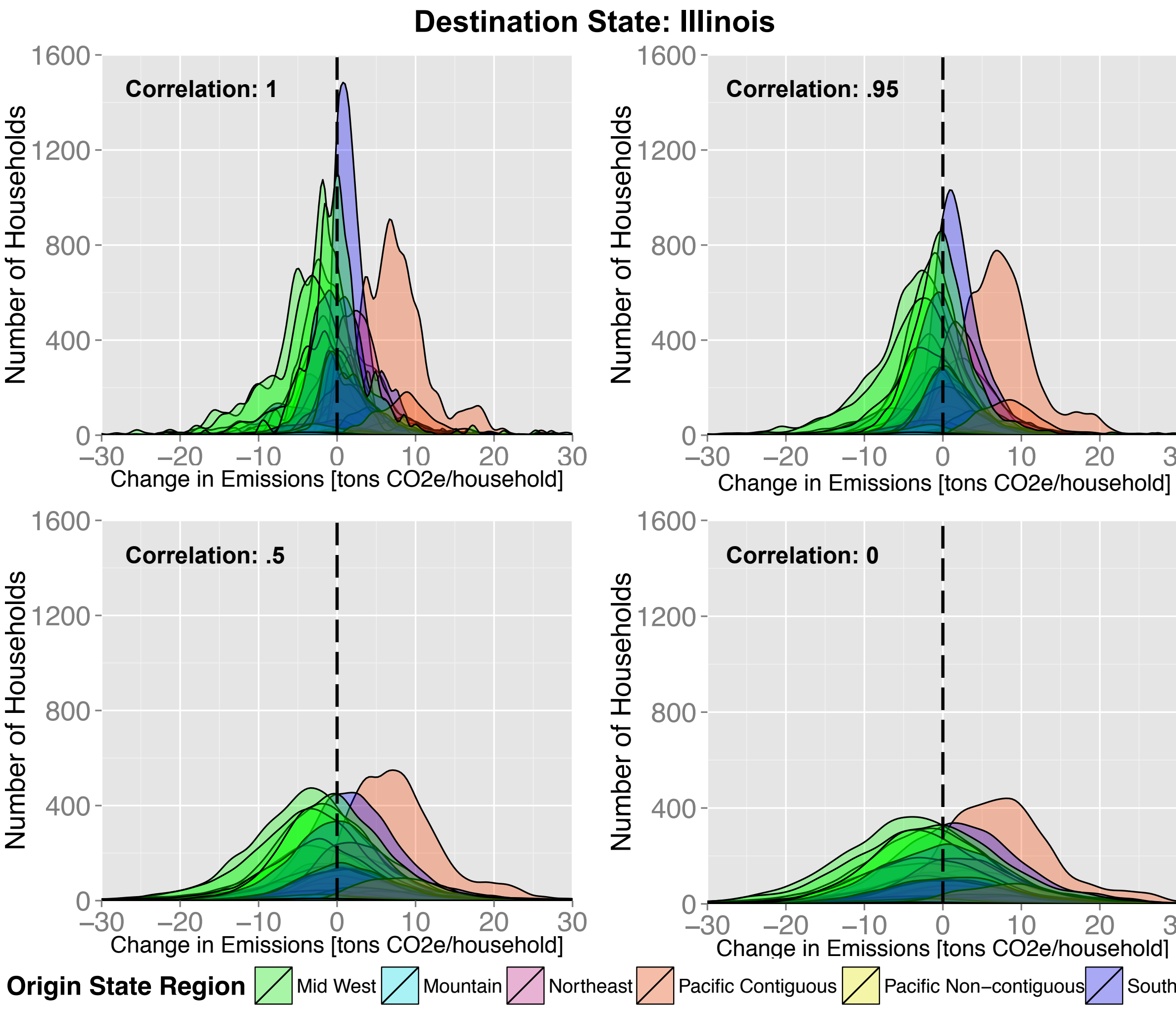
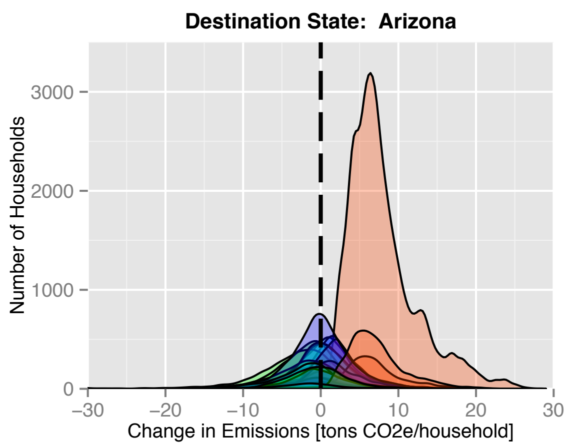
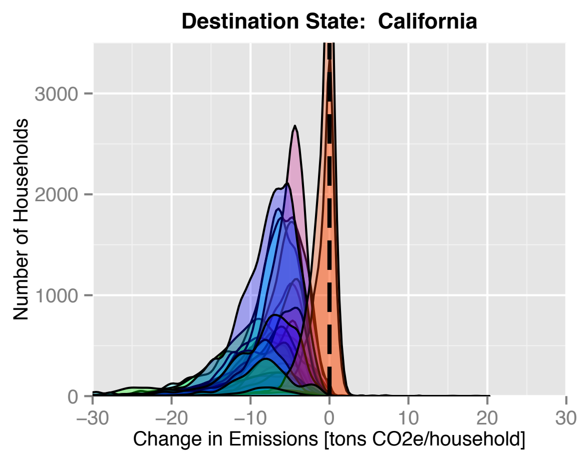


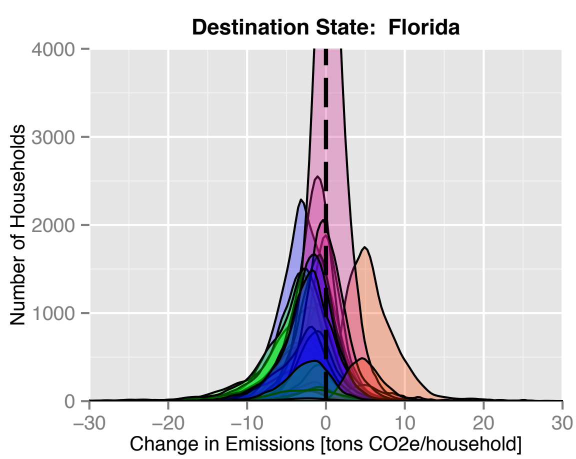
Figure A-2 Distributions of expected household emission changes for households moving to Illinois by origin state using different correlation values to describe the relationship between a household's origin and destination state energy use percentile. The figures show correlation of generated random 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 A-6.

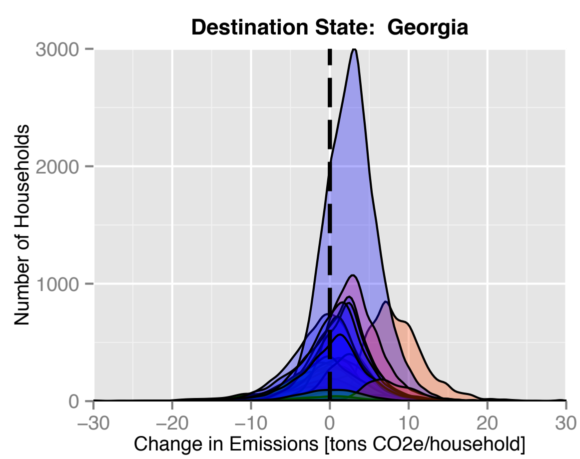
Household Emissions Change Distributions by origin state flows

Similar to Figure 2-6 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.









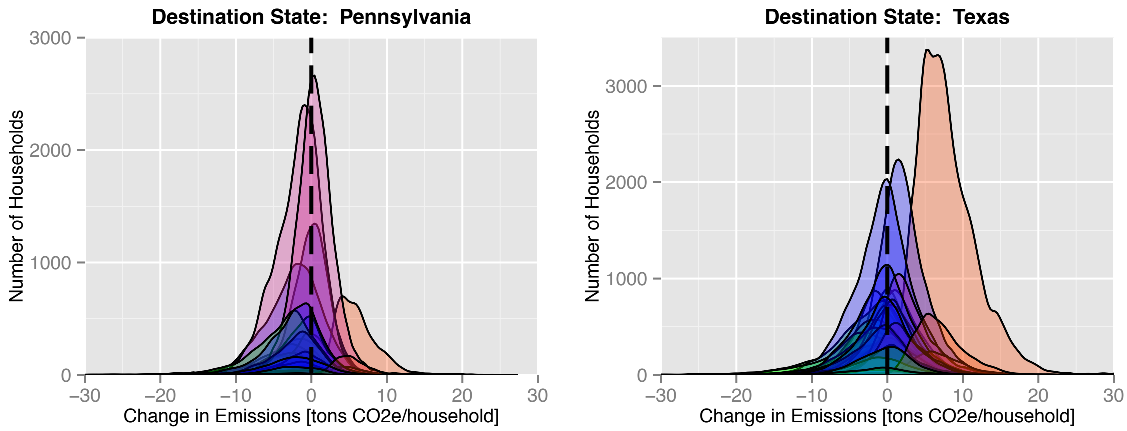


Figure A-3 Distributions of residential emission changes for select destination states

Table A-7 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

Table A-8 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

APPENDIX B. County-County Migration in Pennsylvania

Table A-9 Price of Residential Fuels in Pennsylvania

Fuel	Price	Source
Electricity	0.127 $/kWh	Derived from 2009 RECS Microdata by regressing annual fuel expenditure on annual fuel use (in physical units)
Natural Gas	.0141 $/cuft	
LPG	2.22 $/gal	
Fuel Oil	2.35 $/gal	
Kerosene	2.52 $/gal	
Coal	127 $/ton	(US Energy Information Administration 2010)

Table A-10 Emission Factors for Residential Fuels in PA

Fuel	Emission Factor	Source
Electricity	1.74 lbs CO_2eq/kWh	Eastern Connection (Deru and Torcellini 2006)
Natural Gas	.15 lbs CO_2eq/cuft	(Deru and Torcellini 2006)
LPG	16.6 lbs CO_2eq /gal	
Fuel Oil	30.07 lbs CO_2eq /gal	
Coal	2.93 lbs CO_2eq /ton	

Table A-11 Percent of Homes, by county, using different fuels as primary heating source

	Urban Rural Index	Utility Gas	Electricity	LPG	Fuel Oil	Wood	Coal	Other (Solar, other, none)	% Utility Gas or Electricity	% LPG or Fuel Oil	% Wood, Coal, Other (not solar or None)
Allegheny County	1	86%	11%	1%	2%	0%	0.0%	0.6%	96%	3%	1%
Philadelphia County	1	79%	12%	1%	7%	0%	0.1%	0.6%	91%	8%	0%
Erie County	3	79%	8%	4%	4%	3%	0.1%	1.4%	88%	8%	4%
McKean County	5	79%	6%	2%	3%	6%	2.1%	1.3%	85%	5%	10%
Washington County	2	66%	17%	2%	11%	2%	0.2%	0.6%	84%	13%	3%
Clarion County	6	74%	8%	4%	5%	5%	0.8%	1.8%	83%	9%	8%
Beaver County	2	70%	12%	3%	12%	2%	0.2%	0.5%	82%	15%	3%
Armstrong County	2	74%	7%	3%	11%	3%	0.8%	1.0%	81%	14%	5%

Mercer County	3	64%	16%	2%	12%	4%	0.4%	1.5%	80%	14%	6%
Butler County	2	66%	15%	4%	11%	3%	0.3%	0.7%	80%	16%	4%
Lawrence County	5	59%	20%	2%	15%	2%	0.4%	0.8%	80%	17%	3%
Westmoreland County	2	66%	12%	2%	17%	2%	0.3%	0.6%	78%	19%	3%
Venango County	5	71%	8%	7%	6%	7%	0.4%	0.7%	78%	14%	8%
Elk County	6	70%	8%	4%	8%	8%	2.7%	0.4%	78%	11%	11%
Lackawanna County	3	63%	14%	5%	15%	1%	1.6%	0.4%	77%	20%	3%
Delaware County	2	62%	14%	2%	21%	0%	0.0%	0.7%	76%	23%	1%
Jefferson County	6	70%	5%	6%	10%	5%	3.1%	1.5%	75%	16%	9%
Warren County	5	67%	6%	9%	6%	10%	0.7%	1.6%	73%	15%	12%
Greene County	6	53%	19%	5%	16%	6%	0.6%	0.9%	72%	21%	7%
Montgomery County	2	50%	22%	3%	24%	1%	0.1%	0.5%	72%	27%	1%
York County	3	52%	18%	6%	19%	3%	0.8%	0.8%	70%	26%	4%
Tioga County	6	64%	6%	4%	6%	15%	5.0%	0.4%	69%	10%	20%
Blair County	4	58%	11%	1%	25%	3%	1.2%	0.7%	69%	26%	5%
Potter County	6	60%	7%	7%	3%	16%	5.0%	0.6%	68%	11%	22%
Luzerne County	3	46%	20%	3%	25%	1%	3.7%	0.6%	66%	29%	5%
Dauphin County	3	34%	31%	3%	28%	1%	1.6%	1.1%	65%	31%	4%
Cumberland County	3	30%	35%	4%	27%	3%	1.2%	0.6%	65%	31%	4%
Indiana County	5	51%	14%	5%	22%	4%	2.3%	1.2%	65%	27%	7%
Lehigh County	3	29%	35%	2%	31%	1%	0.8%	0.7%	64%	33%	2%
Bucks County	2	39%	24%	3%	32%	1%	0.2%	0.4%	63%	35%	2%
Franklin County	4	18%	44%	4%	27%	6%	0.6%	1.7%	62%	30%	7%
Cameron County	6	53%	9%	9%	11%	13%	4.2%	1.5%	62%	19%	19%
Lancaster County	3	28%	32%	7%	27%	2%	2.7%	0.7%	60%	34%	6%
Crawford County	5	50%	10%	12%	15%	11%	0.6%	1.8%	60%	27%	13%
Centre County	4	21%	39%	3%	29%	4%	3.0%	1.1%	60%	32%	8%
Northampton County	3	33%	26%	3%	35%	1%	0.9%	1.0%	59%	38%	3%
Chester County	2	31%	27%	10%	29%	1%	0.2%	1.0%	59%	39%	2%
Montour County	4	25%	33%	6%	27%	3%	4.4%	1.0%	59%	33%	8%
Fayette County	2	43%	15%	3%	32%	4%	1.7%	1.1%	58%	35%	6%
Adams County	4	32%	24%	15%	20%	6%	1.4%	1.2%	57%	35%	8%
Cambria County	4	47%	10%	2%	32%	3%	6.3%	0.9%	57%	33%	10%
Forest County	6	50%	6%	14%	12%	16%	0.6%	1.8%	56%	26%	18%
Berks County	3	35%	19%	4%	37%	3%	1.1%	0.8%	54%	41%	4%
Monroe County	4	9%	40%	11%	33%	4%	2.1%	0.9%	49%	43%	7%

Lycoming County	4	29%	19%	3%	38%	7%	3.3%	0.5%	48%	41%	11%
Columbia County	4	23%	25%	5%	38%	4%	4.1%	0.9%	48%	43%	9%
Pike County	2	11%	37%	16%	26%	8%	1.3%	1.2%	47%	42%	10%
Northumberland County	5	23%	23%	3%	41%	3%	6.2%	0.7%	46%	44%	9%
Lebanon County	4	26%	21%	4%	45%	2%	1.2%	0.9%	46%	49%	4%
Union County	5	8%	36%	4%	40%	6%	4.3%	1.2%	44%	44%	12%
Bradford County	5	32%	12%	6%	34%	14%	2.4%	1.0%	43%	40%	17%
Snyder County	5	12%	31%	5%	36%	10%	5.2%	0.9%	42%	41%	16%
Clearfield County	5	25%	10%	5%	49%	3%	7.2%	0.6%	35%	54%	11%
Somerset County	5	18%	16%	4%	45%	5%	12.4%	0.7%	33%	49%	18%
Wayne County	6	12%	20%	14%	39%	11%	3.0%	0.4%	33%	52%	15%
Mifflin County	5	13%	19%	3%	47%	13%	2.5%	1.3%	32%	51%	17%
Clinton County	5	10%	21%	5%	52%	7%	3.7%	1.1%	32%	57%	11%
Carbon County	3	9%	22%	6%	53%	3%	6.2%	0.6%	31%	59%	9%
Perry County	3	1%	27%	7%	45%	13%	5.6%	1.6%	28%	52%	19%
Fulton County	6	1%	26%	4%	47%	20%	0.8%	0.9%	27%	51%	22%
Schuylkill County	5	5%	19%	3%	57%	2%	13.0%	0.6%	24%	60%	15%
Wyoming County	3	3%	20%	15%	47%	9%	4.8%	0.6%	23%	62%	15%
Juniata County	6	2%	21%	6%	48%	19%	2.8%	0.9%	23%	54%	22%
Huntingdon County	5	9%	12%	2%	59%	13%	3.4%	1.8%	20%	61%	18%
Bedford County	6	4%	16%	3%	60%	13%	3.7%	1.0%	20%	62%	18%
Susquehanna County	6	2%	15%	17%	47%	15%	3.2%	0.6%	18%	64%	18%
Sullivan County	6	2%	13%	6%	53%	20%	4.9%	1.8%	15%	59%	27%
Pennsylvania	**-**	**53%**	**20%**	**4%**	**22%**	**3%**	**1%**	**0.8%**	**73%**	**26%**	**4%**

Table A-12 Estimated Annual VMT by County. Summary Statistics for VMT as well county Urban Rural index and the total number of vehicle registration in 2009 by county.

				VMT [mi/vehicle]				
County Name	**Sample Size**	**Registrations 2009**	**UR Index**	**Mean**	**Median**	**5th percentile**	**95th percentile**	**St Dev**
Adams County	5,675	69,283	4	12,947	11,759	2,629	27,333	7,641
Allegheny County	108,955	714,390	1	9,377	8,477	1,073	20,966	6,192
Armstrong County	995	44,938	2	12,690	11,806	2,259	25,588	7,177
Beaver County	11,896	106,542	2	10,367	9,514	1,187	22,594	6,608
Bedford County	333	33,420	6	9,737	9,242	1,269	20,278	5,856
Berks County	23,489	255,120	3	10,457	9,455	1,054	23,529	6,885
Blair County	977	76,181	4	8,662	7,744	1,152	19,784	5,730
Bradford County	99	36,380	5	11,565	10,006	3,003	23,193	6,806
Bucks County	26,655	425,033	2	10,650	9,706	1,219	23,462	6,898
Butler County	14,015	135,670	2	11,390	10,289	984	25,546	7,647
Cambria County	5,830	88,843	4	9,033	7,851	933	21,377	6,525
Cameron County	10	3,002	6	11,648	9,864	7,279	17,907	4,267
Carbon County	1,855	45,283	3	12,845	11,584	2,639	26,679	7,805
Centre County	4,510	71,432	4	10,673	9,794	1,608	22,640	6,621
Chester County	53,476	321,336	2	11,694	10,818	1,924	24,549	6,898
Clarion County	236	21,847	6	11,987	11,399	2,874	23,554	6,488
Clearfield County	175	46,492	5	14,435	14,142	2,876	28,092	8,313
Clinton County	225	20,893	5	12,620	11,862	3,150	25,109	6,951
Columbia County	393	39,512	4	12,468	11,517	3,043	23,822	7,802
Crawford County	3,946	47,301	5	10,505	9,424	1,210	23,935	7,104
Cumberland County	30,905	155,329	3	10,669	9,706	1,652	22,947	6,581
Dauphin County	25,045	187,677	3	10,819	9,849	1,638	23,433	6,723
Delaware County	29,726	337,746	2	9,941	9,115	1,691	21,177	5,980
Elk County	58	19,759	6	11,387	10,653	2,669	21,594	7,427
Erie County	13,445	148,809	3	9,739	8,671	1,281	21,914	6,421
Fayette County	3,226	88,140	2	10,907	9,650	1,240	25,223	7,414
Forest County	78	2,889	6	11,762	11,559	2,717	22,554	6,594
Franklin County	5,310	96,570	4	11,664	10,721	1,896	24,910	6,956
Fulton County	48	9,630	6	15,898	16,081	3,652	30,658	8,675
Greene County	1,126	20,609	6	12,279	10,333	1,396	30,591	9,503
Huntingdon County	195	26,282	5	11,599	10,217	3,022	22,477	5,947
Indiana County	1,790	48,402	5	9,918	8,921	317	22,321	6,725

Jefferson County	84	26,416	6	12,224	11,006	3,996	23,236	6,511
Juniata County	317	14,032	6	14,573	13,033	3,574	32,866	9,076
Lackawanna County	6,966	127,672	3	10,310	9,008	1,224	23,823	7,346
Lancaster County	22,853	309,389	3	10,762	9,508	1,582	24,340	7,114
Lawrence County	5,974	55,112	5	10,691	9,561	1,386	24,519	7,144
Lebanon County	11,670	85,170	4	10,236	9,325	1,466	22,145	6,356
Lehigh County	44,511	220,563	3	10,117	9,006	1,130	23,149	6,778
Luzerne County	16,558	212,081	3	9,542	8,297	763	22,429	7,086
Lycoming County	4,600	71,729	4	9,769	8,688	1,364	21,794	6,372
McKean County	78	22,477	5	12,115	10,914	3,099	23,150	6,577
Mercer County	5,090	65,189	3	9,849	8,924	1,490	21,272	6,085
Mifflin County	2,015	25,823	5	9,720	8,701	1,581	21,237	6,196
Monroe County	8,971	110,637	4	13,419	11,726	1,704	31,602	9,099
Montgomery County	65,751	540,663	2	10,408	9,584	1,516	22,206	6,354
Montour County	191	11,498	4	11,215	9,880	1,784	22,346	6,419
Northampton County	27,955	199,834	3	11,043	9,785	1,193	25,487	7,428
Northumberland County	1,595	57,075	5	10,607	9,392	1,135	24,484	7,582
Perry County	2,058	29,963	3	13,920	13,276	3,297	26,782	7,055
Philadelphia County	30,334	579,728	1	8,937	7,967	1,370	19,829	5,868
Pike County	2,157	40,642	2	14,048	12,270	1,633	32,596	9,658
Potter County	27	9,230	6	9,927	10,997	517	20,594	6,927
Schuylkill County	6,034	94,582	5	10,760	9,455	1,358	24,472	7,419
Snyder County	379	22,565	5	10,058	9,419	1,061	22,907	6,553
Somerset County	5,027	48,061	5	9,367	8,289	718	21,804	6,724
Sullivan County	160	4,018	6	12,599	12,162	3,199	24,739	6,535
Susquehanna County	251	25,322	6	13,555	11,879	2,738	28,792	8,482
Tioga County	79	24,035	6	13,189	11,224	2,255	26,259	8,778
Union County	424	22,105	5	12,070	11,095	1,833	26,046	7,719
Venango County	1,911	31,110	5	9,438	8,562	874	20,983	6,188
Warren County	3,842	23,266	5	10,332	9,385	1,738	21,812	6,295
Washington County	13,110	130,747	2	10,660	9,726	1,098	23,522	6,845
Wayne County	515	34,737	6	13,303	11,936	2,742	27,579	7,840
Westmoreland County	34,578	227,315	2	10,198	9,171	982	23,113	6,959
Wyoming County	1,005	18,573	3	10,123	9,516	24	21,615	6,398
York County	37,280	283,630	3	10,754	9,402	1,448	24,748	7,289
Pennsylvania	739,047	7,549,729	-	10,401	9,347	1,326	23,174	6,809

Table A-13 Estimated Annual fuel economy by County. Summary Statistics for fuel economy as well county Urban Rural index and the total number of vehicle registration in 2009 by county.

				Fuel Economy [mpg]				
Name	Sample Size	Registrations 2009	UR Index	Mean	Median	5th percentile	95th percentile	St Dev
Adams County	5,675	69,283	4	25.7	25.0	16.5	35.3	6.9
Allegheny County	108,955	714,390	1	24.1	24.0	16.3	33.3	5.4
Armstrong County	995	44,938	2	23.9	23.7	16.0	33.5	5.7
Beaver County	11,896	106,542	2	23.2	23.3	16.0	30.6	4.9
Bedford County	333	33,420	6	22.6	22.5	16.0	30.4	5.2
Berks County	23,489	255,120	3	23.4	23.2	16.0	32.5	5.3
Blair County	977	76,181	4	21.8	22.0	15.8	28.8	4.4
Bradford County	99	36,380	5	21.8	20.7	16.0	32.3	6.2
Bucks County	26,655	425,033	2	23.4	23.4	16.0	32.1	5.4
Butler County	14,015	135,670	2	23.1	23.2	16.0	31.5	5.1
Cambria County	5,830	88,843	4	23.2	22.8	16.2	31.5	5.2
Cameron County	10	3,002	6	23.9	23.3	20.4	27.6	2.7
Carbon County	1,855	45,283	3	23.1	22.9	16.0	32.3	5.2
Centre County	4,510	71,432	4	23.4	23.7	16.1	30.5	4.3
Chester County	53,476	321,336	2	23.9	23.5	16.3	34.0	5.8
Clarion County	236	21,847	6	21.8	22.0	15.8	29.9	4.8
Clearfield County	175	46,492	5	23.3	23.5	16.0	29.4	4.6
Clinton County	225	20,893	5	22.6	22.9	15.5	30.5	4.8
Columbia County	393	39,512	4	22.2	21.8	15.5	29.3	5.4
Crawford County	3,946	47,301	5	23.5	23.5	16.0	34.8	6.0
Cumberland County	30,905	155,329	3	24.4	24.1	16.5	34.5	5.7
Dauphin County	25,045	187,677	3	24.6	24.5	16.5	34.0	5.5
Delaware County	29,726	337,746	2	24.8	24.3	17.0	35.0	6.3
Elk County	58	19,759	6	24.2	24.1	16.4	34.1	4.6
Erie County	13,445	148,809	3	23.6	23.0	16.5	33.6	4.8
Fayette County	3,226	88,140	2	22.6	22.5	16.0	30.8	4.9
Forest County	78	2,889	6	21.6	21.0	15.8	29.8	4.5
Franklin County	5,310	96,570	4	24.4	24.0	16.4	34.0	5.4
Fulton County	48	9,630	6	25.0	24.5	18.1	35.0	5.3
Greene County	1,126	20,609	6	21.4	21.1	15.5	29.8	4.7
Huntingdon County	195	26,282	5	22.9	22.8	16.3	32.7	5.1
Indiana County	1,790	48,402	5	23.4	23.3	16.3	31.4	4.8

Jefferson County	84	26,416	6	22.9	23.0	17.6	29.9	3.4
Juniata County	317	14,032	6	24.7	23.8	16.0	35.3	7.2
Lackawanna County	6,966	127,672	3	23.1	23.1	16.0	30.5	4.5
Lancaster County	22,853	309,389	3	25.0	24.5	16.0	35.3	7.1
Lawrence County	5,974	55,112	5	24.1	24.2	16.0	34.8	5.7
Lebanon County	11,670	85,170	4	24.3	24.1	16.3	34.0	5.4
Lehigh County	44,511	220,563	3	23.6	23.7	16.5	31.5	4.7
Luzerne County	16,558	212,081	3	23.2	23.2	16.5	31.2	5.0
Lycoming County	4,600	71,729	4	21.4	21.5	15.5	28.8	4.4
McKean County	78	22,477	5	24.2	24.0	16.7	34.5	5.7
Mercer County	5,090	65,189	3	23.6	23.5	16.0	31.8	4.9
Mifflin County	2,015	25,823	5	23.1	22.5	16.0	33.4	5.9
Monroe County	8,971	110,637	4	23.3	23.0	16.0	34.8	5.9
Montgomery County	65,751	540,663	2	24.9	24.5	17.0	35.0	6.4
Montour County	191	11,498	4	21.3	21.5	14.8	29.0	5.3
Northampton County	27,955	199,834	3	23.4	23.3	16.0	33.0	5.3
Northumberland County	1,595	57,075	5	21.8	21.7	15.5	29.8	4.5
Perry County	2,058	29,963	3	24.3	24.1	16.0	34.8	6.1
Philadelphia County	30,334	579,728	1	25.8	25.6	17.5	35.0	5.6
Pike County	2,157	40,642	2	22.4	21.8	15.8	31.3	5.4
Potter County	27	9,230	6	21.3	21.5	16.1	27.8	4.2
Schuylkill County	6,034	94,582	5	23.3	23.0	16.0	32.3	5.4
Snyder County	379	22,565	5	23.1	22.9	15.8	34.5	5.3
Somerset County	5,027	48,061	5	22.3	22.0	16.0	30.0	5.0
Sullivan County	160	4,018	6	21.2	20.8	15.8	28.8	4.2
Susquehanna County	251	25,322	6	22.3	21.8	16.0	30.5	4.4
Tioga County	79	24,035	6	22.1	21.5	16.0	30.5	5.4
Union County	424	22,105	5	22.1	22.0	15.5	29.8	4.8
Venango County	1,911	31,110	5	22.2	22.0	15.8	29.8	4.5
Warren County	3,842	23,266	5	22.2	22.2	15.8	31.0	4.8
Washington County	13,110	130,747	2	23.4	23.4	16.0	32.5	5.3
Wayne County	515	34,737	6	22.8	22.5	16.0	30.5	5.0
Westmoreland County	34,578	227,315	2	23.2	23.2	16.0	31.5	5.3
Wyoming County	1,005	18,573	3	21.2	21.0	15.5	29.0	4.7
York County	37,280	283,630	3	24.3	24.1	16.3	34.5	5.7
Pennsylvania	739,047	7,549,729	-	24.0	23.7	16.2	33.6	5.6

Table A-14 Estimated Annual fuel economy by County. Summary Statistics for fuel economy as well county Urban Rural index and the total number of vehicle registration in 2009 by county.

				FUEL [Gallons]				
Name	Sample Size	Registrations 2009	UR Index	Mean	Median	5th percentile	95th percentile	St Dev
Adams County	5,675	69,283	4	532	471	106	1,152	341
Allegheny County	108,955	714,390	1	411	354	44	977	298
Armstrong County	995	44,938	2	554	509	95	1,161	343
Beaver County	11,896	106,542	2	466	413	50	1,052	319
Bedford County	333	33,420	6	444	395	70	988	283
Berks County	23,489	255,120	3	468	407	46	1,102	332
Blair County	977	76,181	4	413	351	53	1,014	296
Bradford County	99	36,380	5	544	420	160	1,135	320
Bucks County	26,655	425,033	2	478	421	53	1,107	335
Butler County	14,015	135,670	2	516	451	42	1,220	373
Cambria County	5,830	88,843	4	409	347	39	1,007	316
Cameron County	10	3,002	6	505	415	265	861	224
Carbon County	1,855	45,283	3	577	502	120	1,246	371
Centre County	4,510	71,432	4	475	417	69	1,079	324
Chester County	53,476	321,336	2	514	459	80	1,138	331
Clarion County	236	21,847	6	567	513	132	1,258	326
Clearfield County	175	46,492	5	645	586	135	1,437	406
Clinton County	225	20,893	5	581	516	140	1,313	347
Columbia County	393	39,512	4	578	513	135	1,251	352
Crawford County	3,946	47,301	5	471	406	51	1,122	343
Cumberland County	30,905	155,329	3	459	402	69	1,035	307
Dauphin County	25,045	187,677	3	462	404	66	1,050	313
Delaware County	29,726	337,746	2	423	372	68	953	281
Elk County	58	19,759	6	491	435	117	987	316
Erie County	13,445	148,809	3	429	372	54	1,002	301
Fayette County	3,226	88,140	2	501	433	57	1,191	358
Forest County	78	2,889	6	561	519	134	1,125	333
Franklin County	5,310	96,570	4	497	447	76	1,083	313
Fulton County	48	9,630	6	671	690	157	1,355	411
Greene County	1,126	20,609	6	601	493	64	1,551	502
Huntingdon County	195	26,282	5	528	491	135	1,070	296
Indiana County	1,790	48,402	5	444	390	15	1,051	323

Jefferson County	84	26,416	6	551	476	161	1,094	317
Juniata County	317	14,032	6	615	527	155	1,389	394
Lackawanna County	6,966	127,672	3	465	392	54	1,120	350
Lancaster County	22,853	309,389	3	458	389	63	1,079	332
Lawrence County	5,974	55,112	5	470	400	53	1,123	346
Lebanon County	11,670	85,170	4	439	389	59	987	291
Lehigh County	44,511	220,563	3	444	383	48	1,051	316
Luzerne County	16,558	212,081	3	430	356	32	1,059	343
Lycoming County	4,600	71,729	4	478	410	63	1,125	337
McKean County	78	22,477	5	504	468	136	974	258
Mercer County	5,090	65,189	3	437	389	61	997	290
Mifflin County	2,015	25,823	5	442	388	68	1,021	299
Monroe County	8,971	110,637	4	597	512	75	1,428	420
Montgomery County	65,751	540,663	2	442	390	60	1,001	298
Montour County	191	11,498	4	545	506	85	1,198	327
Northampton County	27,955	199,834	3	492	426	52	1,163	347
Northumberland County	1,595	57,075	5	502	440	50	1,165	377
Perry County	2,058	29,963	3	592	553	138	1,182	317
Philadelphia County	30,334	579,728	1	363	312	51	847	258
Pike County	2,157	40,642	2	644	561	71	1,454	449
Potter County	27	9,230	6	478	472	28	1,033	346
Schuylkill County	6,034	94,582	5	483	414	58	1,136	349
Snyder County	379	22,565	5	450	414	50	1,023	299
Somerset County	5,027	48,061	5	441	373	32	1,066	341
Sullivan County	160	4,018	6	623	545	152	1,412	368
Susquehanna County	251	25,322	6	621	573	121	1,315	388
Tioga County	79	24,035	6	613	501	104	1,329	424
Union County	424	22,105	5	567	511	78	1,180	383
Venango County	1,911	31,110	5	444	380	39	1,022	308
Warren County	3,842	23,266	5	488	434	77	1,082	320
Washington County	13,110	130,747	2	480	421	47	1,106	335
Wayne County	515	34,737	6	602	529	131	1,375	374
Westmoreland County	34,578	227,315	2	460	397	43	1,095	339
Wyoming County	1,005	18,573	3	493	457	1	1,085	326
York County	37,280	283,630	3	462	395	59	1,101	332
Pennsylvania	**739,047**	**7,549,729**	**-**	**455**	**394**	**55**	**1,065**	**323**

Table A-15 Travel Means to work shown in Percent of Workers

	Car, Truck, Van	Public Transit		Car, Truck, Van	Public Transit
Adams County	91.1	0.2	**Lackawanna County**	91.6	1
Allegheny County	80.8	10.1	**Lancaster County**	88.3	1.2
Armstrong County	93	0.3	**Lawrence County**	91	1.1
Beaver County	92.5	1.6	**Lebanon County**	91.8	0.5
Bedford County	91.6	0.2	**Lehigh County**	91	2
Berks County	89.6	1.8	**Luzerne County**	92.9	0.9
Blair County	93	0.5	**Lycoming County**	90.2	1.3
Bradford County	89.1	0.5	**McKean County**	90.9	0.1
Bucks County	90.9	2.8	**Mercer County**	90.5	0.2
Butler County	92.3	0.6	**Mifflin County**	91.3	0.1
Cambria County	91.6	1	**Monroe County**	87.9	5
Cameron County	84.2	0	**Montgomery County**	87.7	4.5
Carbon County	91.7	0.8	**Montour County**	91.3	0.1
Centre County	78.5	3.2	**Northampton County**	91.5	1.4
Chester County	88.8	2.6	**Northumberland County**	91.9	0.2
Clarion County	89.5	0.4	**Perry County**	91.4	0.3
Clearfield County	93.3	0.2	**Philadelphia County**	60.6	25.8
Clinton County	88.6	0.1	**Pike County**	90	2.9
Columbia County	90.6	0.3	**Potter County**	88.5	0.1
Crawford County	86.3	0.6	**Schuylkill County**	92.4	0.5
Cumberland County	90.1	0.8	**Snyder County**	86.6	0.2
Dauphin County	89.7	2.1	**Somerset County**	91	0.2
Delaware County	83.2	8.7	**Sullivan County**	89.6	0.6
Elk County	93.5	0.9	**Susquehanna County**	90.7	0.2
Erie County	90.8	1.4	**Tioga County**	88.2	0.3
Fayette County	94.5	0.2	**Union County**	83.5	0.1
Forest County	89.9	0	**Venango County**	91.7	0.5
Franklin County	91.9	0.3	**Warren County**	89.5	0.4
Fulton County	90.3	0.2	**Washington County**	91.8	1.2
Greene County	92	0.4	**Wayne County**	87.2	0.7
Huntingdon County	88.2	0	**Westmoreland County**	93	1
Indiana County	87.2	0.7	**Wyoming County**	91.2	0.3
Jefferson County	92.2	0.1	**York County**	92.9	1

Juniata County	90.6	0.2			

Table A-16 Number of Reported and Suppressed migration flows in 2009-2001 IRS Migration Files for Pennsylvania, shown in Households by Destination County

Destination County		Origin County Within Pennsylvania				Origin County Outside Pennsylvania			
FIPS	**Name**	**No. Reported**	**Aggregate Total**	**No. Suppressed**	**Percent Reported**	**No. Reported**	**Aggregate Total**	**No. Suppressed**	**Percent Reported**
1	**Adams County**	973	1,126	153	86%	404	894	490	45%
3	**Allegheny County**	8,555	8,643	88	99%	7989	10,176	2,187	79%
5	**Armstrong County**	687	785	98	88%	0	186	186	0%
7	**Beaver County**	1,586	1,713	127	93%	254	967	713	26%
9	**Bedford County**	260	366	106	71%	43	245	202	18%
11	**Berks County**	3,499	3,658	159	96%	976	2,096	1,120	47%
13	**Blair County**	786	907	121	87%	10	530	520	2%
15	**Bradford County**	212	350	138	61%	185	585	400	32%
17	**Bucks County**	6,029	6,135	106	98%	3519	4,829	1,310	73%
19	**Butler County**	2,318	2,424	106	96%	222	1,098	876	20%
21	**Cambria County**	925	1,056	131	88%	22	557	535	4%
23	**Cameron County**	0	52	52	0%	0	25	25	0%
25	**Carbon County**	909	983	74	92%	52	356	304	15%
27	**Centre County**	1,312	1,460	148	90%	360	1,416	1,056	25%
29	**Chester County**	5,750	5,874	124	98%	2691	4,074	1,383	66%
31	**Clarion County**	353	427	74	83%	0	150	150	0%
33	**Clearfield County**	657	830	173	79%	0	344	344	0%
35	**Clinton County**	280	438	158	64%	0	170	170	0%
37	**Columbia County**	638	775	137	82%	0	295	295	0%
39	**Crawford County**	628	749	121	84%	36	433	397	8%
41	**Cumberland County**	3,807	3,935	128	97%	546	1,816	1,270	30%
43	**Dauphin County**	3,780	3,895	115	97%	834	2,016	1,182	41%
45	**Delaware County**	6,073	6,199	126	98%	2422	3,564	1,142	68%
47	**Elk County**	156	218	62	72%	0	99	99	0%
49	**Erie County**	1,024	1,159	135	88%	729	1,980	1,251	37%
51	**Fayette County**	856	987	131	87%	106	629	523	17%
53	**Forest County**	38	87	49	44%	0	24	24	0%
55	**Franklin County**	814	960	146	85%	705	1,423	718	50%

57	**Fulton County**	111	155	44	72%	48	102	54	47%
59	**Greene County**	224	286	62	78%	61	278	217	22%
61	**Huntingdon County**	339	458	119	74%	0	151	151	0%
63	**Indiana County**	635	790	155	80%	0	494	494	0%
65	**Jefferson County**	462	583	121	79%	0	171	171	0%
67	**Juniata County**	196	269	73	73%	0	54	54	0%
69	**Lackawanna County**	1,664	1,759	95	95%	469	1,242	773	38%
71	**Lancaster County**	3,795	3,893	98	97%	1336	2,761	1,425	48%
73	**Lawrence County**	558	630	72	89%	80	419	339	19%
75	**Lebanon County**	1,476	1,632	156	90%	64	623	559	10%
77	**Lehigh County**	4,400	4,510	110	98%	1986	3,053	1,067	65%
79	**Luzerne County**	2,139	2,240	101	95%	993	1,942	949	51%
81	**Lycoming County**	840	1,005	165	84%	0	600	600	0%
83	**McKean County**	126	229	103	55%	80	278	198	29%
85	**Mercer County**	698	808	110	86%	265	772	507	34%
87	**Mifflin County**	278	382	104	73%	0	167	167	0%
89	**Monroe County**	1,127	1,195	68	94%	1608	2,220	612	72%
91	**Montgomery County**	11,796	11,924	128	99%	4117	5,645	1,528	73%
93	**Montour County**	286	385	99	74%	0	151	151	0%
95	**Northampton County**	3,451	3,556	105	97%	1822	2,717	895	67%
97	**Northumberland County**	1,065	1,162	97	92%	0	285	285	0%
99	**Perry County**	675	766	91	88%	0	133	133	0%
101	**Philadelphia County**	11,765	11,875	110	99%	13318	15,186	1,868	88%
103	**Pike County**	324	382	58	85%	829	1,089	260	76%
105	**Potter County**	75	188	113	40%	31	127	96	24%
107	**Schuylkill County**	1,338	1,437	99	93%	11	487	476	2%
109	**Snyder County**	428	521	93	82%	0	141	141	0%
111	**Somerset County**	452	581	129	78%	47	334	287	14%
113	**Sullivan County**	45	108	63	42%	0	40	40	0%
115	**Susquehanna County**	260	343	83	76%	106	352	246	30%
117	**Tioga County**	205	344	139	60%	59	327	268	18%
119	**Union County**	442	554	112	80%	0	239	239	0%
121	**Venango County**	434	498	64	87%	0	264	264	0%
123	**Warren County**	179	275	96	65%	78	299	221	26%
125	**Washington County**	2,116	2,257	141	94%	338	1,236	898	27%
127	**Wayne County**	582	647	65	90%	249	558	309	45%

129	**Westmoreland County**	3,536	3,646	110	97%	353	1,487	1,134	24%
131	**Wyoming County**	391	456	65	86%	0	155	155	0%
133	**York County**	3,363	3,501	138	96%	2136	3,453	1,317	62%
-	**Pennsylvania**	**115,181**	**122,421**	**7,240**	**94%**	**52,589**	**91,009**	**38,420**	**58%**

Table A-17 County FIPS Codes

Name	FIPS	Name	FIPS	Name	FIPS	Name	FIPS
Adams County	1	Clinton County	35	Lackawanna County	69	Pike County	103
Allegheny County	3	Columbia County	37	Lancaster County	71	Potter County	105
Armstrong County	5	Crawford County	39	Lawrence County	73	Schuylkill County	107
Beaver County	7	Cumberland County	41	Lebanon County	75	Snyder County	109
Bedford County	9	Dauphin County	43	Lehigh County	77	Somerset County	111
Berks County	11	Delaware County	45	Luzerne County	79	Sullivan County	113
Blair County	13	Elk County	47	Lycoming County	81	Susquehanna County	115
Bradford County	15	Erie County	49	McKean County	83	Tioga County	117
Bucks County	17	Fayette County	51	Mercer County	85	Union County	119
Butler County	19	Forest County	53	Mifflin County	87	Venango County	121
Cambria County	21	Franklin County	55	Monroe County	89	Warren County	123
Cameron County	23	Fulton County	57	Montgomery County	91	Washington County	125
Carbon County	25	Greene County	59	Montour County	93	Wayne County	127
Centre County	27	Huntingdon County	61	Northampton County	95	Westmoreland County	129
Chester County	29	Indiana County	63	Northumberland County	97	Wyoming County	131
Clarion County	31	Jefferson County	65	Perry County	99	York County	133
Clearfield County	33	Juniata County	67	Philadelphia County	101		

Table A-18 Supplemented IRS OD Matrix. Rows represent origin counties. Columns represent Destination Counties. Part 1 Destination Counties : FIPS 1 - 43

FIPS	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45
1	0	14	0	0	0	0	0	0	0	0	0	0	0	15	19	0	0	10	0	0	146	52	0
3	13	0	182	885	25	34	61	10	65	1266	81	10	0	83	63	51	32	11	0	108	60	89	72
5	0	237	0	0	0	0	0	0	0	146	0	0	0	0	0	75	0	0	0	0	0	0	0
7	0	826	0	0	0	0	0	10	0	267	10	0	0	0	0	0	0	0	0	13	0	12	0
9	0	26	0	0	0	0	99	0	0	0	38	0	0	13	0	0	0	0	0	0	10	0	0
11	10	65	0	0	0	0	0	0	112	0	0	0	17	41	411	0	0	0	0	0	47	96	65
13	0	98	0	0	150	13	0	0	0	13	185	0	0	113	11	0	55	8	0	0	24	18	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	17	11	0
17	0	68	0	0	0	173	0	14	0	0	13	0	48	35	304	0	0	0	29	0	39	37	241
19	0	1012	148	272	0	0	11	0	0	0	0	0	0	18	0	63	0	0	0	23	0	23	0
21	0	209	0	0	29	0	187	10	11	13	0	0	0	34	10	0	52	0	0	0	26	30	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	23	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	13	0
27	0	127	0	0	0	23	83	10	30	15	26	0	0	0	28	0	189	109	0	10	35	55	16
29	15	77	0	0	0	467	13	10	207	11	0	0	0	48	0	0	0	10	12	0	43	54	1153
31	0	54	65	0	0	0	0	4	0	69	0	7	0	0	0	0	14	0	0	10	0	0	0
33	0	53	0	0	0	0	50	0	0	0	53	10	0	204	0	16	0	10	0	0	0	15	0
35	0	0	0	0	0	0	11	10	0	0	0	0	0	111	0	0	0	0	0	0	0	13	0
37	0	11	0	0	0	12	0	10	12	0	0	0	0	0	14	0	0	10	0	0	0	14	0

FIPS	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45
39	0	111	0	11	0	0	0	0	0	29	0	0	0	0	0	0	0	10	0	0	0	0	0
41	82	83	0	0	18	34	32	0	33	0	15	0	0	42	59	0	0	10	13	0	0	1158	27
43	39	106	0	0	0	63	20	10	37	0	12	0	0	36	69	0	0	0	11	0	1334	0	31
45	0	67	0	0	0	83	0	0	241	0	0	0	13	21	1687	0	0	9	10	0	27	39	0
47	0	33	0	0	0	0	0	0	0	0	0	21	0	15	0	0	46	0	0	0	0	0	0
49	0	275	0	37	0	14	0	0	13	51	0	10	0	29	19	23	13	0	0	300	15	23	0
51	0	228	0	15	0	0	0	6	0	11	0	0	0	10	0	0	0	0	0	0	0	0	0
53	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	22	0	0	0	0	0	0	0
55	105	47	0	0	17	10	0	0	0	0	11	0	0	15	19	0	0	10	0	0	317	33	0
57	0	0	0	0	28	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
59	0	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	0	11	0	0	45	0	83	0	0	0	12	0	0	69	0	0	0	5	0	0	30	15	0
63	0	192	91	0	0	0	15	0	0	20	122	0	0	17	0	0	26	0	0	0	11	18	10
65	0	48	14	0	0	0	0	4	0	18	0	0	0	0	0	74	215	0	0	0	0	0	0
67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	31	0
69	0	32	0	0	0	13	0	19	16	0	0	0	10	13	28	0	0	0	22	0	22	34	24
71	25	79	0	0	13	361	11	10	64	0	28	0	0	45	473	0	22	0	12	0	166	457	91
73	0	159	0	156	0	0	0	10	0	146	0	0	0	0	0	0	0	6	0	0	0	0	0
75	13	27	0	0	0	221	0	0	16	0	0	0	0	13	27	0	0	10	0	0	79	471	10
77	0	47	0	0	0	492	0	0	298	0	0	0	234	38	90	0	0	0	13	0	36	50	50

FIPS	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45
79	0	37	0	0	0	57	0	17	49	0	0	0	115	23	54	0	0	5	254	0	41	72	45
81	0	33	0	0	0	16	13	16	0	0	0	0	0	49	10	0	0	211	46	0	33	72	21
83	0	36	0	0	0	0	0	0	0	0	0	6	0	0	0	0	12	6	0	0	0	0	0
85	0	179	12	26	0	0	0	0	0	135	0	0	0	0	0	18	0	10	0	130	0	0	0
87	0	0	0	0	0	13	14	0	0	0	0	0	0	48	0	0	0	10	0	0	28	28	0
89	0	17	0	0	0	24	0	1	38	0	0	0	158	10	36	0	0	4	12	0	22	21	26
91	0	134	0	0	0	966	0	10	2519	13	10	0	58	57	1973	0	14	10	13	0	68	87	1132
93	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	127	0	10	11	0
95	0	30	0	0	0	138	0	0	170	0	0	0	184	18	52	0	0	6	0	0	21	27	25
97	0	15	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	2	109	0	35	86	0
99	0	0	0	0	0	0	0	3	0	0	0	0	0	10	0	0	0	0	0	0	374	229	0
101	11	207	0	0	0	245	0	19	2834	12	18	0	44	45	721	0	0	0	22	0	63	120	3839
103	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
105	0	16	0	0	0	0	0	4	0	0	0	2	0	10	0	0	0	2	0	0	0	0	0
107	0	19	0	0	0	202	0	0	27	0	0	0	140	16	15	0	0	7	38	0	41	156	22
109	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	15	0	14	28	0
111	0	95	0	0	29	0	15	0	0	0	294	0	0	10	0	0	0	0	0	0	12	0	0
113	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
117	0	0	0	0	0	0	0	48	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0

FIPS	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45
119	0	11	0	0	0	0	0	5	0	0	0	0	0	23	0	0	0	10	18	0	14	12	0
121	0	84	0	11	0	0	0	0	0	72	0	0	0	0	0	85	0	0	0	100	0	0	0
123	0	38	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	27	0	0	0
125	0	1189	0	55	0	0	0	0	0	49	16	8	0	13	11	0	0	0	0	0	12	10	0
127	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
129	0	1903	279	47	0	13	20	0	14	127	71	0	0	29	11	16	0	0	0	10	16	25	0
131	0	0	0	0	0	0	0	52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
133	704	95	0	11	0	74	19	0	37	0	20	0	0	39	73	0	0	12	10	0	884	477	38
Column Sum	1017	8628	791	1526	354	3784	757	380	6879	2483	1035	84	1021	1503	6287	443	690	528	786	731	4211	4322	6938
IRS Reported Sum	1017	8628	791	1526	354	3784	757	263	6879	2483	1035	21	1021	1503	6287	443	690	343	786	731	4211	4322	6938
IRS Aggregate	**1142**	**8705**	**886**	**1680**	**448**	**3908**	**925**	**351**	**7004**	**2644**	**1171**	**65**	**1087**	**1633**	**6430**	**540**	**873**	**529**	**888**	**853**	**4308**	**4428**	**7054**
IRS % Reported	89%	99%	89%	91%	79%	97%	82%	75%	98%	94%	88%	32%	94%	92%	98%	82%	79%	65%	89%	86%	98%	98%	98%
Supplemental % Reported	89%	99%	89%	91%	79%	97%	82%	108%	98%	94%	88%	129%	94%	92%	98%	82%	79%	100%	89%	86%	98%	98%	98%

Table A-19 Supplemented IRS OD Matrix. Rows represent origin counties. Columns represent Destination Counties. Part 1 Destination Counties : FIPS 45-87

FIPS	45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81	83	85	87
1	0	0	0	0	0	145	0	0	0	0	0	0	0	28	0	0	0	0	0	0	0	0
3	72	15	173	140	12	25	0	38	16	98	45	6	20	56	128	19	39	20	25	14	129	0
5	0	10	12	0	0	0	0	0	0	98	22	0	0	0	0	0	0	0	0	2	0	0
7	0	0	19	16	10	0	0	0	0	0	0	0	0	0	154	0	0	0	0	0	20	0
9	0	0	0	0	3	27	30	0	36	0	0	0	0	11	0	0	0	0	0	6	0	0
11	65	0	0	0	10	24	0	0	0	0	0	10	16	460	0	324	395	56	15	10	0	0
13	0	0	14	0	0	13	0	0	74	15	0	0	0	22	0	0	0	0	0	0	0	11
15	0	0	0	0	0	0	0	0	0	0	0	0	14	17	0	0	0	24	35	9	0	0
17	241	0	0	0	0	11	0	0	0	0	0	5	19	122	0	26	340	62	17	0	0	0
19	0	3	53	10	10	0	0	0	0	13	0	0	0	11	141	0	11	0	0	0	152	0
21	0	10	11	0	0	18	0	0	11	141	10	0	0	26	0	0	0	0	0	0	0	0
23	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	219	139	0	0	0	0
27	16	10	16	0	0	0	0	0	48	10	11	10	12	39	0	11	19	16	39	0	0	62
29	1153	0	0	0	0	0	0	0	0	0	0	5	14	718	0	39	77	29	14	0	0	0
31	0	10	19	0	25	0	0	0	0	0	64	0	0	0	0	0	0	0	0	5	17	0
33	0	36	14	0	0	0	0	0	12	39	211	0	0	11	0	0	0	0	0	3	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	196	10	0	0

FIPS	45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81	83	85	87
37	0	0	0	0	0	0	0	0	0	0	0	10	21	15	0	0	17	232	31	0	0	0
39	0	0	350	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	121	0
41	27	7	11	0	0	288	0	0	27	0	0	20	15	146	0	88	29	22	16	0	0	16
43	31	0	13	0	0	49	0	0	11	0	0	21	13	448	0	562	43	22	38	0	0	18
45	0	0	0	0	10	0	0	0	0	0	0	10	12	146	0	13	47	20	13	0	0	0
47	0	0	17	0	0	0	0	0	0	0	45	0	0	0	0	0	0	0	0	23	0	0
49	0	10	0	0	10	0	0	0	0	11	0	0	0	0	17	0	11	0	0	20	45	0
51	0	0	0	0	0	0	0	74	0	13	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	8	0	59	0	63	0	0	7	0	40	0	0	0	0	0	0	0	0
57	0	0	0	0	0	72	0	0	18	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0	0	0	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	0	0	0	0	0	29	19	0	0	0	0	0	0	13	0	0	0	0	0	0	0	92
63	10	0	16	10	4	0	0	0	0	0	103	0	0	18	0	0	0	0	0	10	0	0
65	0	46	19	0	9	0	0	0	0	60	0	0	0	10	0	0	0	0	0	7	0	0
67	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	62
69	24	0	0	0	0	0	0	0	0	0	0	0	0	18	0	0	33	473	15	0	0	0
71	91	6	0	0	0	20	0	0	15	14	0	12	15	0	0	387	52	34	17	10	0	19
73	0	0	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	161	0
75	10	0	0	0	0	15	0	0	0	0	0	4	0	327	0	0	26	0	0	0	0	0

FIPS	45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81	83	85	87
77	50	0	13	0	0	0	0	0	0	0	0	0	43	62	0	24	0	103	12	0	0	0
79	45	0	0	0	0	0	0	0	0	0	0	0	487	38	0	16	109	0	17	0	0	0
81	21	10	16	0	6	10	0	0	0	0	0	4	16	41	0	12	12	37	0	2	0	0
83	0	25	25	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
85	0	0	55	0	10	0	0	0	0	0	0	0	0	0	130	0	0	0	0	10	0	0
87	0	10	0	0	0	12	0	0	59	0	0	67	0	17	0	0	0	0	12	10	0	0
89	26	0	0	0	0	0	0	0	0	0	0	7	140	29	0	0	160	151	0	8	0	0
91	1132	0	11	12	0	21	0	0	0	0	0	0	37	194	0	36	304	45	19	0	0	0
93	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	22	0	0	0
95	25	0	0	0	0	0	0	0	0	0	0	0	29	49	0	10	2263	51	0	5	0	0
97	0	0	0	0	0	0	0	0	0	0	0	10	0	30	0	15	10	42	117	2	0	0
99	0	0	0	0	0	0	0	0	0	0	0	47	0	26	0	15	0	0	0	0	0	15
101	3839	0	25	0	10	22	0	0	0	14	0	10	66	196	0	31	182	105	30	0	0	0
103	0	0	0	0	0	0	0	0	0	0	0	0	57	0	0	0	14	17	0	0	0	0
105	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	45	0	0
107	22	0	0	0	0	0	0	0	0	0	0	0	16	51	0	86	85	222	15	10	0	0
109	0	0	0	0	0	0	0	0	0	0	0	42	0	19	0	0	0	0	20	0	0	32
111	0	0	0	50	0	10	0	0	0	16	0	0	0	11	0	0	0	0	0	10	0	0
113	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36	3	0	0
115	0	0	0	0	0	0	0	0	0	0	0	0	153	0	0	0	0	35	0	1	0	0

FIPS	45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81	83	85	87
117	0	10	0	0	0	0	0	0	0	0	0	0	0	18	0	0	0	0	49	10	0	0
119	0	2	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	51	7	0	0
121	0	10	62	0	12	0	0	0	0	0	0	0	0	0	12	0	0	0	0	5	67	0
123	0	10	114	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	0	0
125	0	9	19	196	0	0	0	143	0	0	0	0	0	0	0	0	0	0	0	6	16	0
127	0	0	0	0	0	0	0	0	0	0	0	0	281	11	0	0	0	37	0	0	0	0
129	0	10	31	406	0	0	0	23	0	216	14	0	0	25	16	0	0	0	0	10	19	0
131	0	0	0	0	0	0	0	0	0	0	0	0	164	0	0	0	0	133	0	0	0	0
133	38	0	16	0	0	62	0	0	0	0	0	10	14	571	0	57	35	33	24	0	0	10
Column Sum	6938	271	1162	910	163	873	108	278	390	758	525	318	1685	4132	598	1771	4532	2182	895	319	747	337
IRS Reported Sum	6938	134	1162	910	59	873	108	278	390	758	525	219	1685	4132	598	1771	4532	2182	895	138	747	337
IRS Aggregate	**7054**	**212**	**1268**	**1016**	**103**	**1028**	**139**	**322**	**510**	**941**	**630**	**300**	**1757**	**4238**	**705**	**1889**	**4644**	**2301**	**1039**	**242**	**876**	**432**
IRS % Reported	98%	63%	92%	90%	57%	85%	78%	86%	76%	81%	83%	73%	96%	97%	85%	94%	98%	95%	86%	57%	85%	78%
Supplemental % Reported	98%	128%	92%	90%	158%	85%	78%	86%	76%	81%	83%	106%	96%	97%	85%	94%	98%	95%	86%	132%	85%	78%

Table A-20 Supplemented IRS OD Matrix. Rows represent origin counties. Columns represent Destination Counties. Part 1 Destination Counties: FIPS 89-113

FIPS	89	91	93	95	97	99	101	103	105	107	109	111	113	115	117	119	121	123	125	127	129	131	133
1	0	16	0	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	775
3	11	139	0	23	11	0	280	0	14	0	0	52	0	0	10	11	60	18	1512	0	2050	0	58
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	7	10	0	225	0	0
7	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	12	7	72	0	49	0	0
9	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0
11	21	808	0	91	15	0	263	0	0	294	0	0	0	0	11	0	0	0	0	0	14	0	90
13	0	11	0	0	0	0	19	0	10	0	0	0	9	0	0	0	0	0	0	0	17	0	18
15	0	17	0	0	0	0	15	0	0	0	0	0	25	23	48	0	0	2	0	0	0	38	0
17	48	2563	0	207	0	0	2355	20	6	35	0	0	0	12	17	0	0	4	0	18	12	0	29
19	0	10	0	0	0	0	12	0	0	0	0	11	0	0	3	0	41	10	38	0	92	0	0
21	0	17	0	0	0	0	15	0	0	0	0	220	0	0	10	0	0	0	15	0	89	0	15
23	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	105	35	0	134	0	0	35	0	0	182	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	70	0	18	14	0	80	0	10	11	0	0	3	0	10	18	0	10	0	0	21	0	35
29	21	1798	0	42	0	0	703	0	7	20	0	0	0	0	14	0	0	0	0	0	16	0	62
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	66	2	0	0	11	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0	16
35	0	0	0	0	15	0	11	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	12

FIPS	89	91	93	95	97	99	101	103	105	107	109	111	113	115	117	119	121	123	125	127	129	131	133
37	0	12	137	13	144	0	22	0	0	31	0	0	6	0	0	19	0	1	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	99	32	15	0	11	0	0
41	0	54	0	22	22	338	83	0	10	18	12	10	0	0	10	0	0	0	10	0	12	0	725
43	17	66	0	18	81	237	157	0	5	134	29	0	0	0	5	12	0	0	0	0	17	0	394
45	17	1152	0	24	14	0	2773	0	0	12	0	0	0	0	10	0	0	10	0	0	12	0	30
47	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49	0	22	0	0	0	0	23	0	0	0	0	0	0	0	10	0	33	104	14	0	45	0	21
51	0	0	0	0	0	0	0	0	0	0	0	38	0	0	0	0	0	0	211	0	444	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	15	0	0	0	0	0
55	0	23	0	0	0	14	26	0	3	0	0	0	0	0	9	0	0	0	0	0	0	0	49
57	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	149	0	0	0	0
61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0
63	0	10	0	0	0	0	14	0	10	0	0	11	0	0	0	0	0	0	18	0	231	0	10
65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	15	0	0
67	0	0	0	0	0	37	0	0	0	0	36	0	0	0	0	0	0	0	0	0	0	0	11
69	67	62	0	19	0	0	103	28	0	13	0	0	10	148	0	0	0	0	0	223	0	161	17
71	13	174	0	22	32	32	242	0	15	51	11	0	0	0	12	14	0	0	12	0	19	0	556
73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	6	0	0	10	0	0
75	0	29	0	0	12	19	36	0	0	77	0	0	0	0	0	0	0	0	0	0	10	0	63

FIPS	89	91	93	95	97	99	101	103	105	107	109	111	113	115	117	119	121	123	125	127	129	131	133
77	99	311	0	2219	15	0	219	15	0	122	0	0	0	0	0	0	0	0	0	0	0	0	43
79	90	85	20	52	26	0	131	15	0	240	0	0	0	26	10	12	0	0	0	26	0	118	35
81	10	29	25	11	124	0	44	0	2	15	11	0	15	0	45	65	0	0	0	0	0	0	34
83	0	0	0	0	0	0	0	0	42	0	0	0	0	0	10	0	0	18	0	0	0	0	0
85	0	0	0	0	0	0	12	0	0	0	0	0	0	0	5	0	51	10	0	0	19	0	0
87	0	0	0	0	0	10	0	0	8	0	21	0	0	0	0	0	0	0	0	0	0	0	10
89	0	57	0	385	10	0	78	106	0	23	0	0	0	0	0	0	0	0	0	52	0	0	17
91	48	0	0	103	16	0	3375	0	0	44	0	11	0	0	16	0	0	0	0	12	19	0	74
93	0	0	0	0	95	0	0	0	0	0	12	0	0	0	2	18	0	0	0	0	0	0	0
95	314	144	0	0	10	0	130	22	0	45	0	0	0	0	6	0	0	5	0	0	0	0	23
97	0	13	117	0	0	0	27	0	0	74	193	0	0	0	0	256	0	0	0	0	0	0	22
99	0	0	0	0	14	0	0	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	60
101	56	4543	0	92	30	0	0	0	0	31	0	0	0	0	17	0	0	4	0	12	22	0	80
103	156	0	0	31	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	126	0	0	0
105	0	0	0	0	0	0	0	0	0	0	0	0	0	0	57	0	0	0	0	0	0	0	0
107	17	55	0	42	106	0	45	0	3	0	0	0	0	0	3	0	0	0	0	0	0	0	21
109	0	0	12	0	203	18	0	0	0	0	0	0	0	0	0	99	0	0	0	0	0	0	15
111	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	80	0	0
113	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	37	0	69	0

FIPS	89	91	93	95	97	99	101	103	105	107	109	111	113	115	117	119	121	123	125	127	129	131	133
117	0	12	0	0	0	0	0	0	48	0	0	0	0	0	0	0	0	0	0	0	0	0	0
119	0	10	20	0	267	0	13	0	2	0	108	0	0	0	7	0	0	0	0	0	0	0	0
121	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	16	0	0
123	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	0	0	0	0	0	0
125	0	0	0	0	0	0	0	0	0	0	0	19	0	0	0	0	0	0	0	0	241	0	0
127	26	10	0	14	0	0	14	85	7	0	0	0	0	36	0	0	0	10	0	0	0	0	0
129	0	16	0	0	0	0	36	0	0	0	0	86	0	0	0	0	10	7	273	0	0	0	14
131	0	0	0	0	0	0	0	0	0	0	0	0	3	71	0	0	0	0	0	0	0	0	0
133	0	70	0	18	24	62	108	0	0	22	13	12	0	0	10	0	0	0	17	0	21	0	0
Column Sum	1136	12443	331	3600	1300	767	11551	291	225	1494	463	500	71	316	387	524	422	308	2377	506	3854	386	3434
IRS Reported Sum	1136	12443	331	3600	1300	767	11551	291	119	1494	463	500	40	316	257	524	422	203	2377	506	3854	386	3434
IRS Aggregate	**1228**	**12571**	**437**	**3700**	**1389**	**868**	**11673**	**365**	**216**	**1590**	**547**	**605**	**99**	**399**	**363**	**644**	**495**	**303**	**2530**	**602**	**3943**	**457**	**3578**
IRS % Reported	93%	99%	76%	97%	94%	88%	99%	80%	55%	94%	85%	83%	40%	79%	71%	81%	85%	67%	94%	84%	98%	84%	96%
Supplemental % Reported	93%	99%	76%	97%	94%	88%	99%	80%	104%	94%	85%	83%	72%	79%	107%	81%	85%	102%	94%	84%	98%	84%	96%

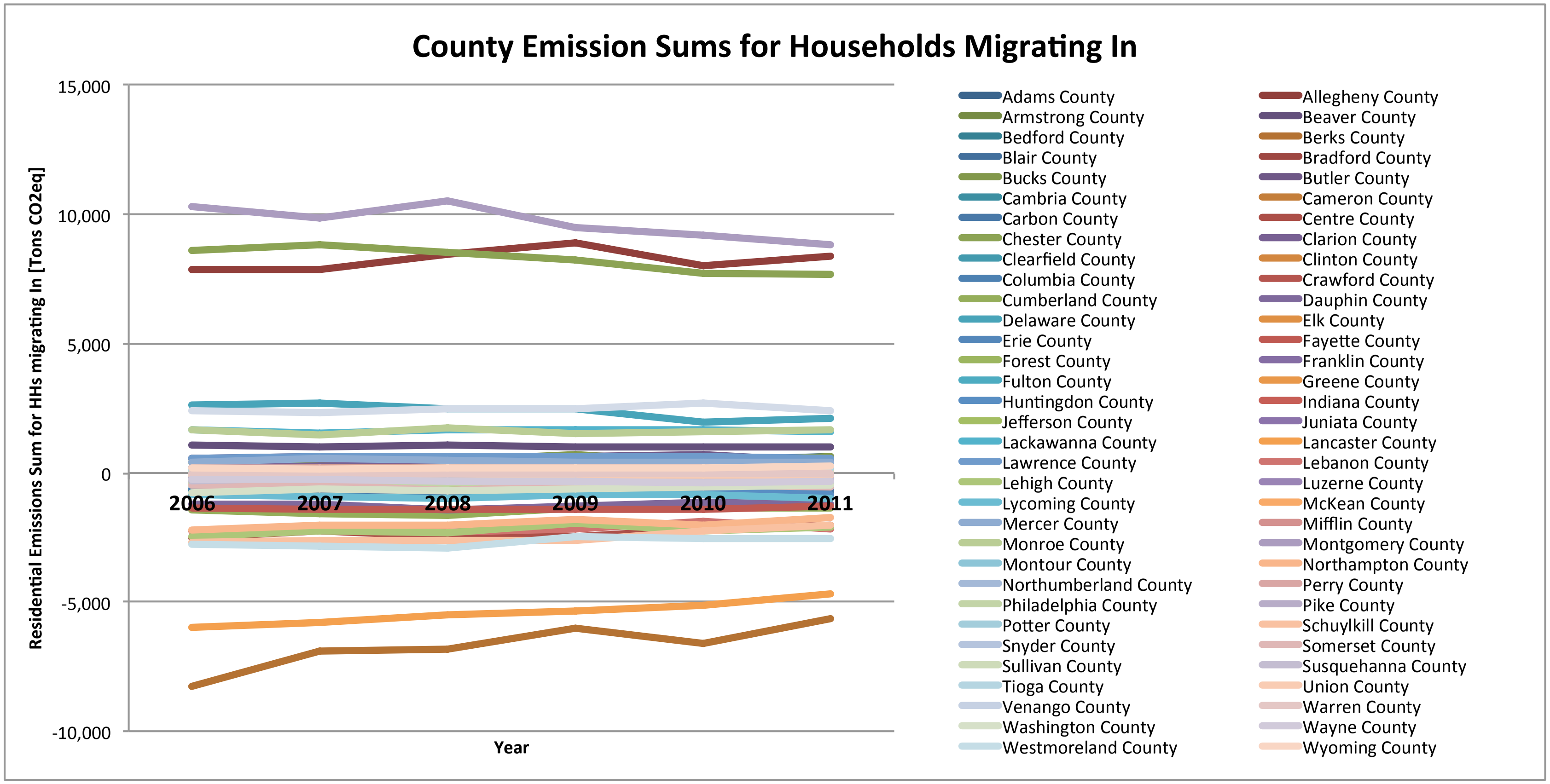


Figure A-4 Residential emissions sums of household migrating into counties overtime, using the BTU method. The 3 outlying counties with positive emission sums include Montgomery County, Chester County, and Allegheny County. The 2 outlying counties with negative emissions sums include Berks County and Lancaster County.

Table A-21 Emission Sums for Destination Counties (shown in tons CO_2eq) for BTU and Income method

County	BTU	Income	County	BTU	Income
Adams County	571	831	Lackawanna County	1640	-482
Allegheny County	8458	-11548	Lancaster County	-5514	-9014
Armstrong County	-876	-351	Lawrence County	638	1559
Beaver County	1047	2283	Lebanon County	-2290	-4600
Bedford County	-463	128	Lehigh County	-2319	-4315
Berks County	-6826	-8380	Luzerne County	0	-880
Blair County	451	-699	Lycoming County	-997	-1358
Bradford County	-5	-31	McKean County	83	-286
Bucks County	506	3419	Mercer County	469	615
Butler County	632	-1650	Mifflin County	-3	393
Cambria County	-568	824	Monroe County	1712	994
Cameron County	5	-32	Montgomery County	10492	1133
Carbon County	-783	-307	Montour County	-48	-175
Centre County	-2440	-3985	Northampton County	-2039	-3439
Chester County	8558	2178	Northumberland County	-304	-1142
Clarion County	310	16	Perry County	204	93
Clearfield County	-191	731	Philadelphia County	-393	-17,852
Clinton County	-154	257	Pike County	-151	31
Columbia County	-667	-185	Potter County	58	-123
Crawford County	-322	447	Schuylkill County	-2604	6432
Cumberland County	-1643	-7439	Snyder County	-120	57
Dauphin County	-1431	-4998	Somerset County	-679	975
Delaware County	2503	1082	Sullivan County	43	-46
Elk County	176	-294	Susquehanna County	-209	133
Erie County	-229	-2282	Tioga County	140	55
Fayette County	-1403	-808	Union County	-56	59
Forest County	17	-90	Venango County	6	-105
Franklin County	-32	-551	Warren County	-59	130
Fulton County	-93	22	Washington County	-720	-1110
Greene County	-82	-96	Wayne County	-335	308
Huntingdon County	-437	249	Westmoreland County	-2934	-5082
Indiana County	-97	-930	Wyoming County	198	201
Jefferson County	-405	490	York County	2496	-3965
Juniata County	-210	78	Pennsylvania	282	-72427

Table A-22 Total Household Emission Sums for Destination Counties shown in Tons CO_2eq

	Transportation	Residential Energy		Total Household	
		BTU	Income	BTU	Income
Adams County	2,222	571	831	2,793	3,053
Allegheny County	-17,857	8,458	-11,548	-9,399	-29,405
Armstrong County	1,405	-876	-351	529	1,054
Beaver County	710	1,047	2,283	1,757	2,993
Bedford County	133	-463	128	-330	261
Berks County	869	-6,826	-8,380	-5,957	-7,511
Blair County	-832	451	-699	-381	-1,531
Bradford County	15	-5	-31	10	-16
Bucks County	22,362	506	3,419	22,868	25,781
Butler County	10,019	632	-1,650	10,651	8,369
Cambria County	-751	-568	824	-1,319	73
Cameron County	-13	5	-32	-8	-45
Carbon County	2,287	-783	-307	1,504	1,980
Centre County	-2,382	-2,440	-3,985	-4,822	-6,367
Chester County	15,062	8,558	2,178	23,620	17,240
Clarion County	179	310	16	489	195
Clearfield County	1,804	-191	731	1,613	2,535
Clinton County	436	-154	257	282	693
Columbia County	1,208	-667	-185	541	1,023
Crawford County	176	-322	447	-146	623
Cumberland County	-2,040	-1,643	-7,439	-3,683	-9,479
Dauphin County	2,378	-1,431	-4,998	947	-2,620
Delaware County	9,742	2,503	1,082	12,245	10,824
Elk County	-81	176	-294	95	-375
Erie County	-913	-229	-2,282	-1,142	-3,195
Fayette County	1,074	-1,403	-808	-329	266
Forest County	148	17	-90	165	58
Franklin County	203	-32	-551	171	-348
Fulton County	394	-93	22	301	416
Greene County	495	-82	-96	413	399
Huntingdon County	543	-437	249	106	792
Indiana County	-666	-97	-930	-763	-1,596
Jefferson County	162	-405	490	-243	652

Juniata County	623	-210	78	413	701
Lackawanna County	-3,157	1,640	-482	-1,517	-3,639
Lancaster County	-1,897	-5,514	-9,014	-7,411	-10,911
Lawrence County	-33	638	1,559	605	1,526
Lebanon County	-922	-2,290	-4,600	-3,212	-5,522
Lehigh County	-5,443	-2,319	-4,315	-7,762	-9,758
Luzerne County	-2,573	0	-880	-2,573	-3,453
Lycoming County	-349	-997	-1,358	-1,346	-1,707
McKean County	-82	83	-286	1	-368
Mercer County	-893	469	615	-424	-278
Mifflin County	-760	-3	393	-763	-367
Monroe County	3,305	1,712	994	5,017	4,299
Montgomery County	17,698	10,492	1,133	28,190	18,831
Montour County	216	-48	-175	168	41
Northampton County	3,541	-2,039	-3,439	1,502	102
Northumberland County	-740	-304	-1,142	-1,044	-1,882
Perry County	1,851	204	93	2,055	1,944
Philadelphia County	-56,509	-393	-17,852	-56,902	-74,361
Pike County	693	-151	31	542	724
Potter County	-289	58	-123	-231	-412
Schuylkill County	-571	-2,604	6,432	-3,175	5,861
Snyder County	-437	-120	57	-557	-380
Somerset County	193	-679	975	-486	1,168
Sullivan County	182	43	-46	225	136
Susquehanna County	500	-209	133	291	633
Tioga County	475	140	55	615	530
Union County	671	-56	59	615	730
Venango County	-378	6	-105	-372	-483
Warren County	-13	-59	130	-72	117
Washington County	3,208	-720	-1,110	2,488	2,098
Wayne County	1,123	-335	308	788	1,431
Westmoreland County	1,607	-2,934	-5,082	-1,327	-3,475
Wyoming County	396	198	201	594	597
York County	-541	2,496	-3,965	1,955	-4,506
Pennsylvania	9,186	282	-72,427	9,468	-63,241

Commuting

Commuting data is available in the ACS. The ACS tracks daily commute time, means of transportation, arrival and departure time to work and other related variables for each person in a household. Limited analysis is conducted on commuting time to work.

Just as personal vehicle use varied by county, so does average commute time to work. Figure A-5 shows average commute time in minutes, for persons traveling by car, truck, or bus for Pennsylvania counties. Average commute time varies by county from 20 minutes to 38 minutes and is the longest for very rural counties in central PA and counties close to New York-Newark area. Commute time is also larger for counting surrounding the largest urban centers. The use of public transit to travel work is generally is uncommon in most counties in Pennsylvania. In Delaware County, Allegheny County Philadelphia County 9%, 10% and 26% of workers travel to work by public transit. 7 other counties have transit ridership between 2 and 4.5% for workers while the remaining counties have transit ridership less than 2%.

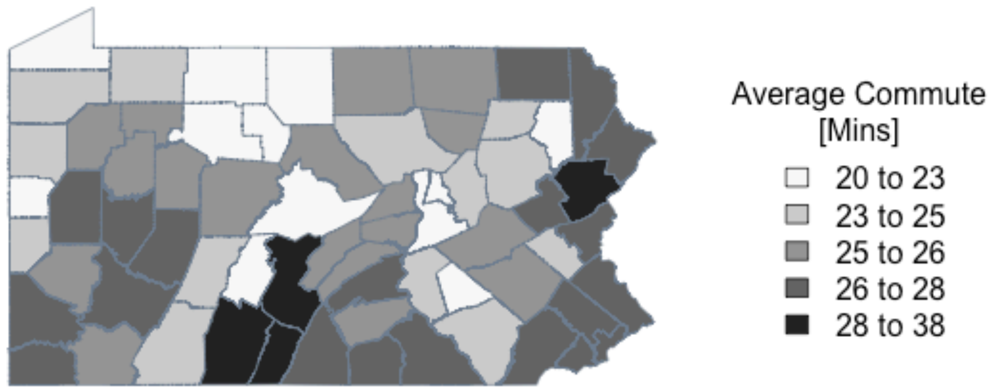
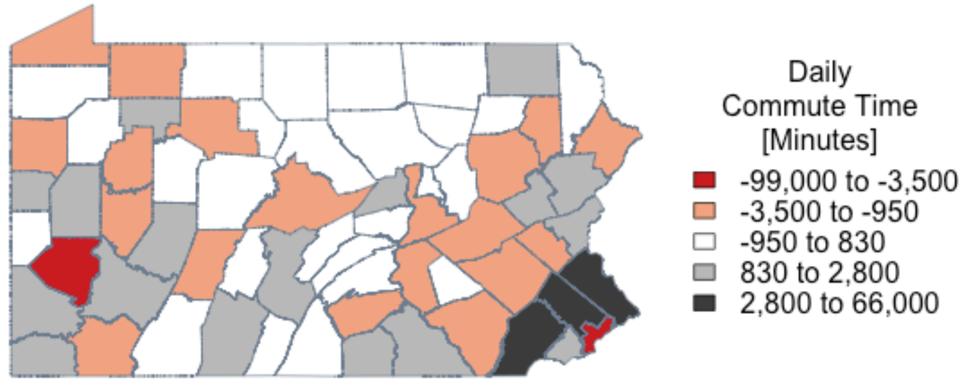
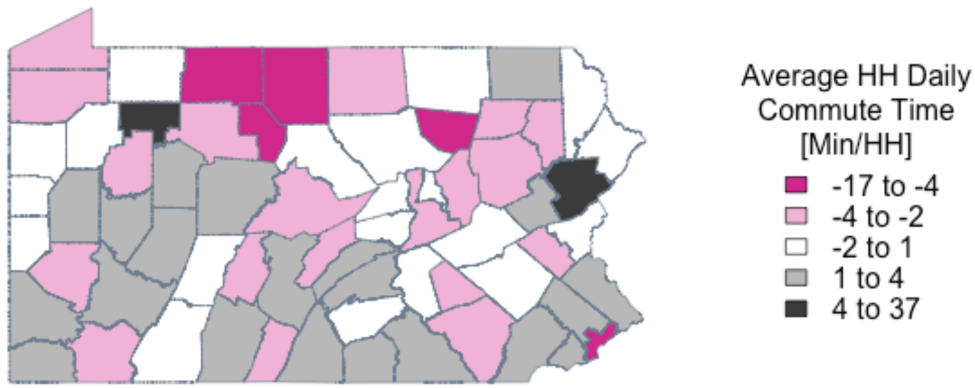


Figure A-5 Average Commute time to work for those traveling by car, truck, or van.

Changes in total VMT for migrating households is similar to the total changes in commute time for migrating households, shown in Figure A-6a. The sum of daily commute minutes increases for household moving to fringe counties while they decrease for household moving to urban centers.



a)



b)

Figure A-6 Changes in daily work commute time for migrating household in Pennsylvania in a) the sum of commute time changes for all households moving into each county and b) average change of all households moving to each county

APPENDIX C. HISTORICAL FOOTPRINTING OF ALLEGHENY COUNTY, SUPPLEMENTARY INFORMATION

Pennsylvania State Electricity Mix

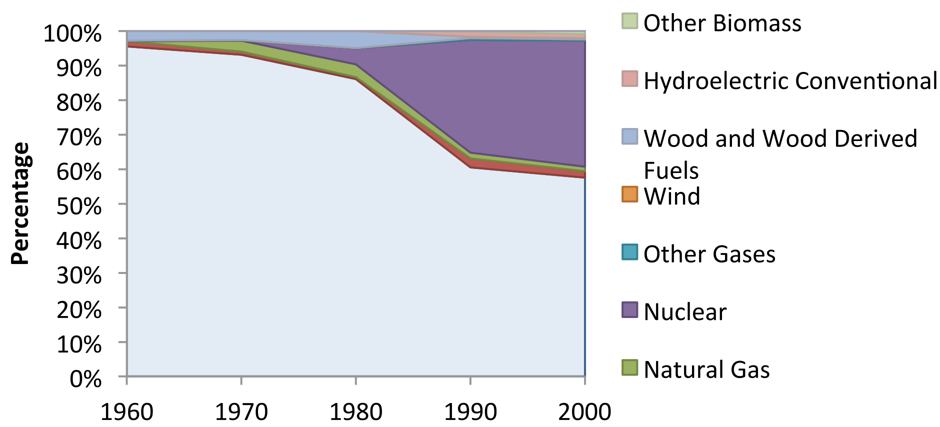


Figure A-7. Electricity mix for Pennsylvania, 1960 to 2000 (US EIA, 2010)

Commercial Intensities

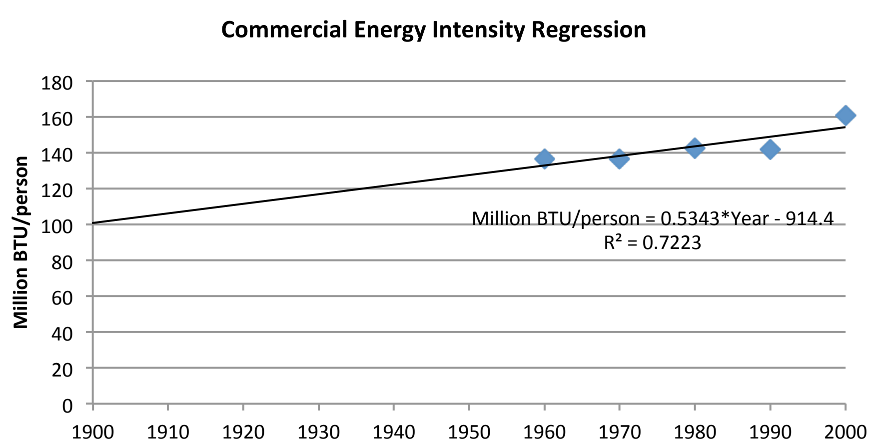


Figure A-8 Regression for commercial energy consumption per employee based on Pennsylvania energy consumption data.

Because the regression is heavily influenced by the 2000 data point, we also performed calculations using a constant energy intensity of 136 Million BTU/employee for 1900 to 1960. This influence the 1900 values the most and 1950 the least. It increased the value of commercial CO_2 emissions in 1900 by 30%, but increased the total Allegheny County Emissions by only 5%.

Waterborne Transportation

Energy intensity [BTU/ton-mile] for waterborne freight transportation was obtained from the US Department of Transportation Data book for 1975 – 2006 (Davis et al. 2009). Energy Intensity did not follow a particular trend from the 70's onward.

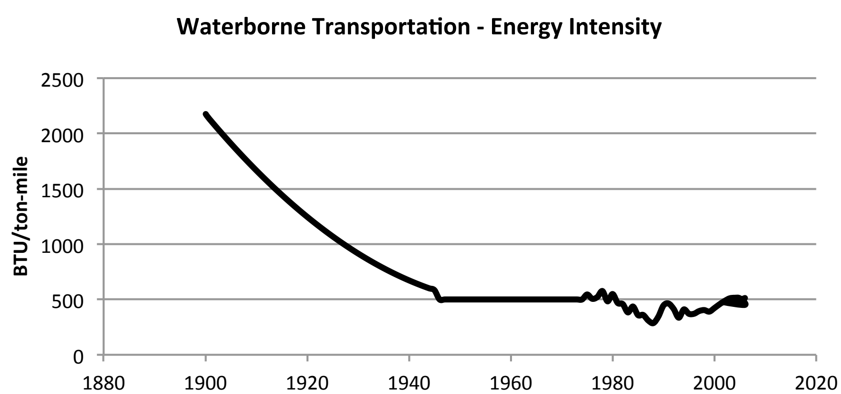


Figure A-9 shows estimates for intensity, I, in BTU/ton-mile, for waterborne commerce in the US accounting for efficiencies of steam engines from 1900 to 1950

Waterborne transportation used steam engines before 1940, but by 1945 engines were dominated by diesel fuel. There was no data available for energy intensity or energy use for waterborne transportation by steam engine. We assumed that Energy Intensity, not accounting for efficiency, stayed constant at 500 BTU/ton-mile. Using these values, we obtained the figure below that shows the Energy Intensity for Waterborne Freight Transportation accounting for efficiency of steam engines shown in Figure 3.

Intensities and Allocation factors: Data Sources and Methodology

Table A-23 Commercial Sector A and I

Year	A: Commercial Sector Employees	I: Commercial Sector Energy Use/employee
1900	Summation of commercial employment in Pittsburgh, Allegheny City, and Mckeesport, Scaled up to Allegheny County by population (US Census Bureau 1904)	Linear Regression (detailed in figure 2)
1910-1920	Commercial employment data for Pittsburgh. Scaled up to Allegheny county by population (US Census Bureau 1913, 1923)	
1930	Allegheny County commercial sector employment. (US Census Bureau 1932)	
1940	Allegheny County commercial sector employment. (US Census Bureau 1943)	
1950	Difference of Commercial employment in Pittsburgh Metropolitan Statistical Area and areas outside Allegheny County including Aliquippa, Ambridge, Arnold, Beaver Falls, and New Kensington (US Census Bureau 1952)	
1960	United States Census of Population and Housing (Geolytics 1996, Geolytics 2006a, Geolytics 2006b, U.S. Census Bureau 1963)	SEDS (EIA 2010)

Table A-24 Intensities, I and Data Sources

<table>
<tr><th>.</th><th>Residential
[energy consumption/ Household]</th><th>Commercial
[energy consumption/ sector employee]</th><th>Industrial
[energy/ sector employee]</th><th>Rail
[Rail Freight energy/ miles operating rail line]</th><th>Highway
[Fuel consumption/person]</th><th>Water
[energy/ ton-mile of good transported]</th><th>Air
[air transportation energy/ person]</th></tr>
<tr><td>1900</td><td rowspan="5">National
(Morrison 1992)</td><td rowspan="6">Linear Regression shown in Figure 2</td><td rowspan="5">Assumed equal to 1950, energy estimate only reflects change in employees</td><td rowspan="11">National
(Department of Transportation Bureau of Transportation Statistics 2009</td><td rowspan="3">Assumed equal to 1930 value, energy estimate only reflects change in population</td><td rowspan="5">National (Estimate shown in figure 3)</td><td rowspan="6"></td></tr>
<tr><td>1910</td></tr>
<tr><td>1920</td></tr>
<tr><td>1930</td><td rowspan="8">State (Department of Transportation 2008)</td></tr>
<tr><td>1940</td></tr>
<tr><td>1950</td><td>National
(EIA Annual Energy Review)</td><td rowspan="6">National (US Census Bureau 1947, EIA Manufacturing Energy Consumption Survey)</td><td rowspan="6">National (Davis et al 2009)</td></tr>
<tr><td>1960</td><td rowspan="5">State
(SEDS)</td><td rowspan="5">State
(SEDS)</td><td rowspan="5">National (Davis et al 2009)</td></tr>
<tr><td>1970</td></tr>
<tr><td>1980</td></tr>
<tr><td>1990</td></tr>
<tr><td>2000</td></tr>
</table>

Energy Use Estimates

Table A-25 Total Energy Estimates

[Billion MJ]							
Year	Residential	Commercial	Industrial	Transportation			
				Rail	Highway	Water	Air
1900	29	26	89.27	7.4	8.7	1.67	-
1910	41	27	85.80	9.2	11	1.28	-
1920	43	35	84.11	9.7	13	1.05	-
1930	43	34	136.01	9.4	16	.99	-
1940	51	39	183.31	8.4	26	.99	-
1950	62	42	173.31	7.5	37	1.01	-
1960	110	50	168.10	1.9	54	1.38	4.9
1970	120	53	180.94	2.0	68	1.62	19
1980	128	67	121.60	2.4	68	1.84	18
1990	110	74	106.36	2.5	61	1.46	23
2000	110	74	94.73	3.5	63	1.27	24

Table A-26 Energy Consumed per Capita

[Thousand MJ]							
Year	Residential	Commercial	Industrial	Transportation			
				Rail	Highway	Water	Air
1900	37	34	115	9.6	11	2.2	-
1910	40	27	84	9.1	11	1.3	-
1920	36	30	71	8.2	11	0.9	-
1930	31	25	99	6.9	11	0.7	-
1940	36	27	130	6.0	19	0.7	-
1950	41	28	114	5.0	24	0.7	-
1960	65	31	103	1.2	33	0.8	3.0
1970	77	33	113	1.2	42	1.0	12
1980	88	46	84	1.7	47	1.3	13
1990	81	55	80	1.9	46	1.1	17
2000	88	58	74	2.8	49	1.0	19

Alternative Industrial Allocating factors

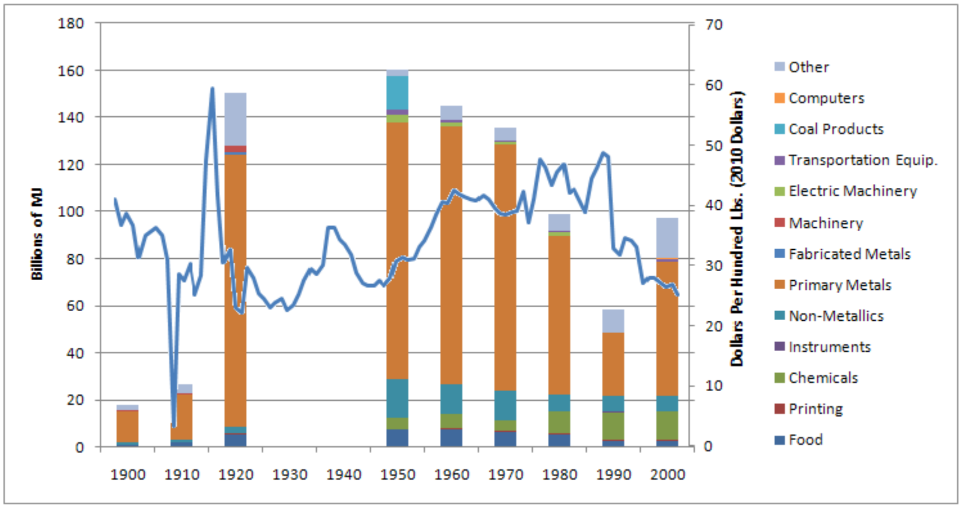


Figure A-10. Estimated Allegheny County Industrial Energy Use, scaled by alternative allocating factor, Value Added

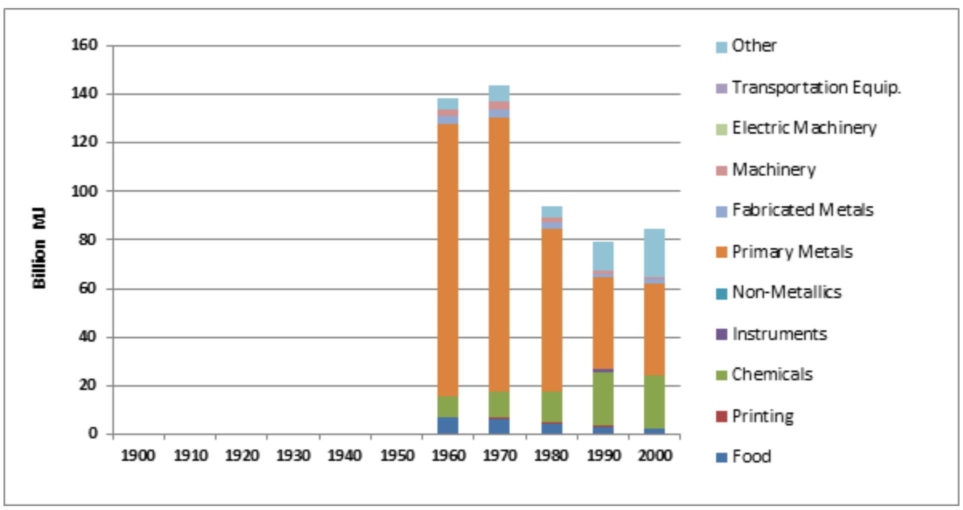


Figure A-11 Estimated Allegheny County Industrial Energy Use, scaled by alternative allocating factor, Production Workers

State Inventories

Using the methodology described in this paper for calculating emissions from energy use, emissions inventories were estimated for all 50 states using energy data only from EIA SEDS database (US EIA, 2006) and emission factors from EIA Voluntary Reporting of GHG Program (EIA). Because total energy use is available from SEDS for each state, no allocating factors or energy intensities were needed for these estimates. Some inventories are shown in Figure 6.

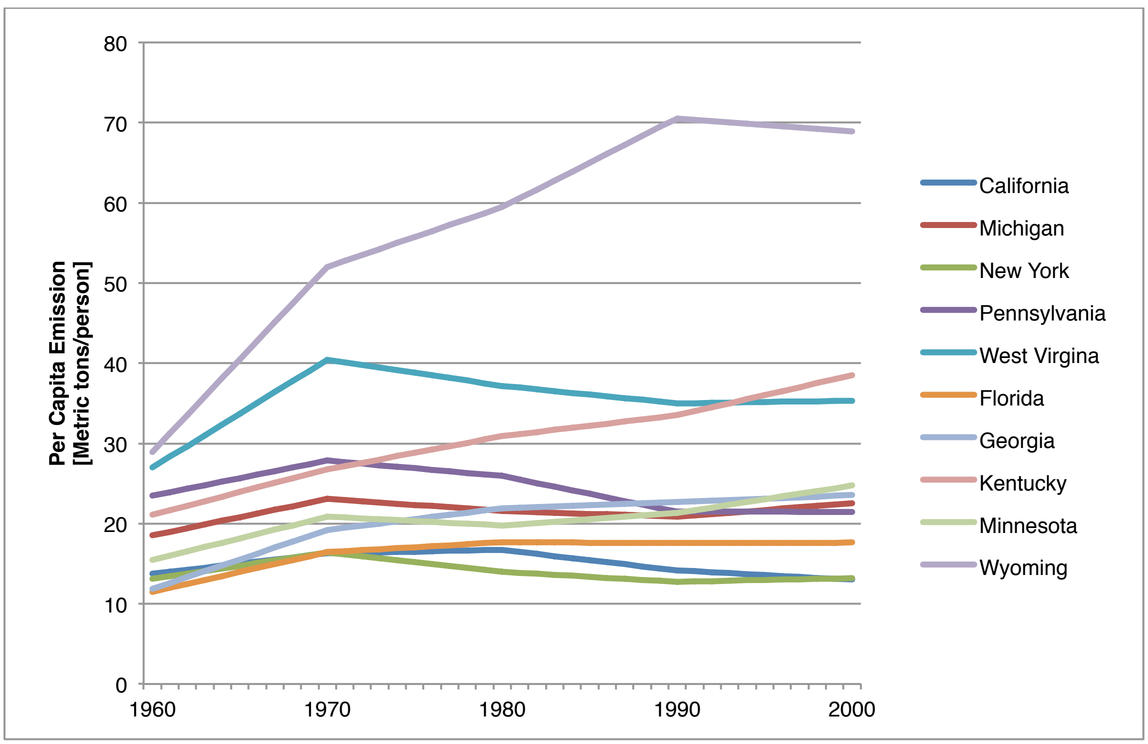


Figure A-12 Per Capita CO_2 emission inventories for selected states.