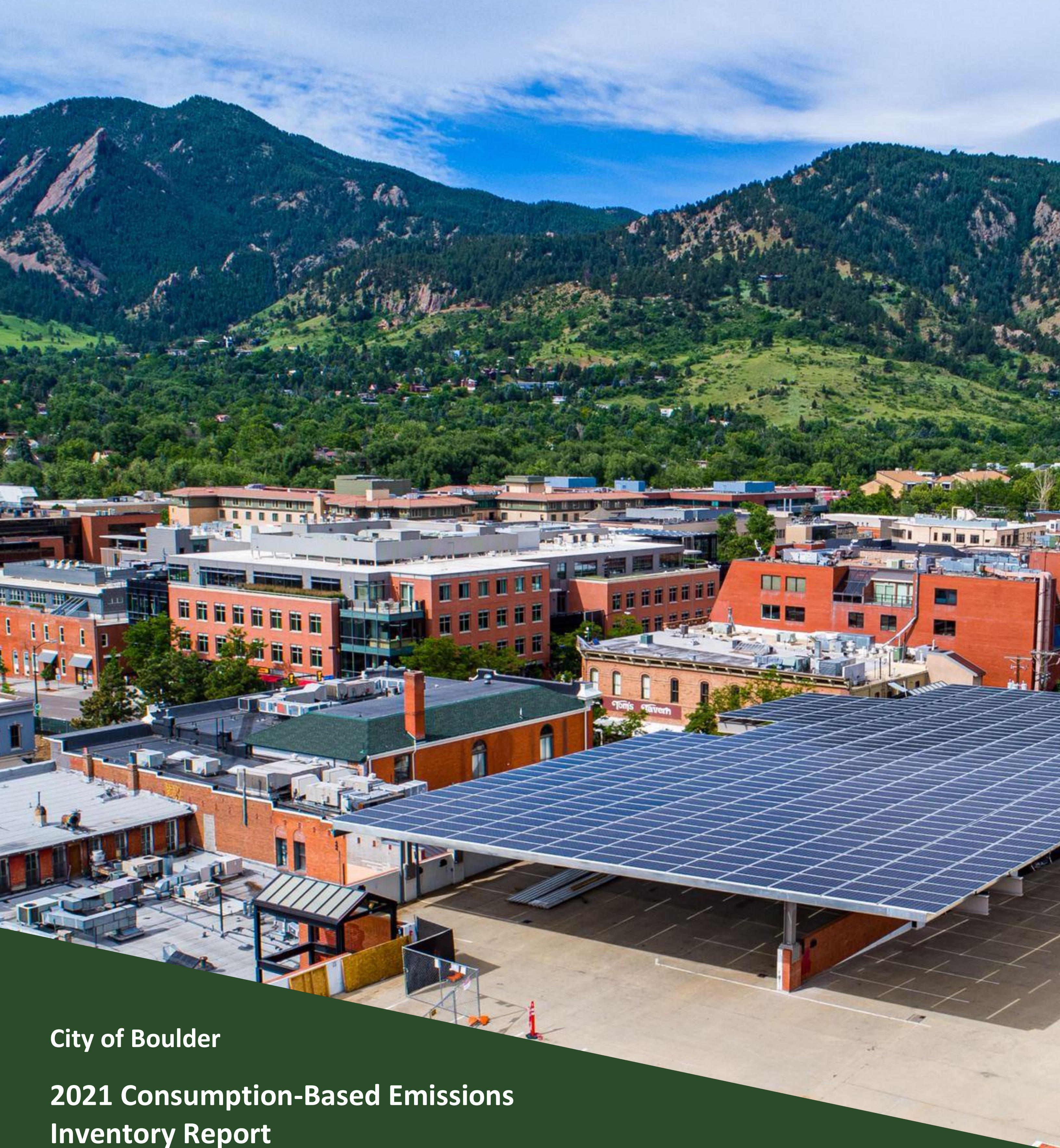

City of Boulder

2021 Consumption-Based Emissions Inventory Report

Prepared August 2023

EcoDataLab

CITY OF BOULDER

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Glossary

Category	CBEI emissions are categorized into 5 categories: transportation, housing, food, goods, services
CBEI	Consumption-based emissions inventory - an estimate of the greenhouse gas emissions associated with the activity of all residents of a geographic area
Emissions	Refers to greenhouse gas emissions (see *GHG*)
GHG	Greenhouse gas - a gas that absorbs and emits radiant energy within the thermal infrared range, causing the greenhouse effect
$MTCO_2e$	Metric tonne (i.e. 1,000 kilograms) of carbon dioxide equivalent – the common unit for GHG emissions
Per Capita Emissions	GHG emissions per person
"Use phase" emissions	The burning of fossil fuels (such as gasoline or natural gas) for transportation or home heating energy
Sub-category	Each CBEI emissions category consists of multiple sub-categories
VMT	Vehicle miles traveled

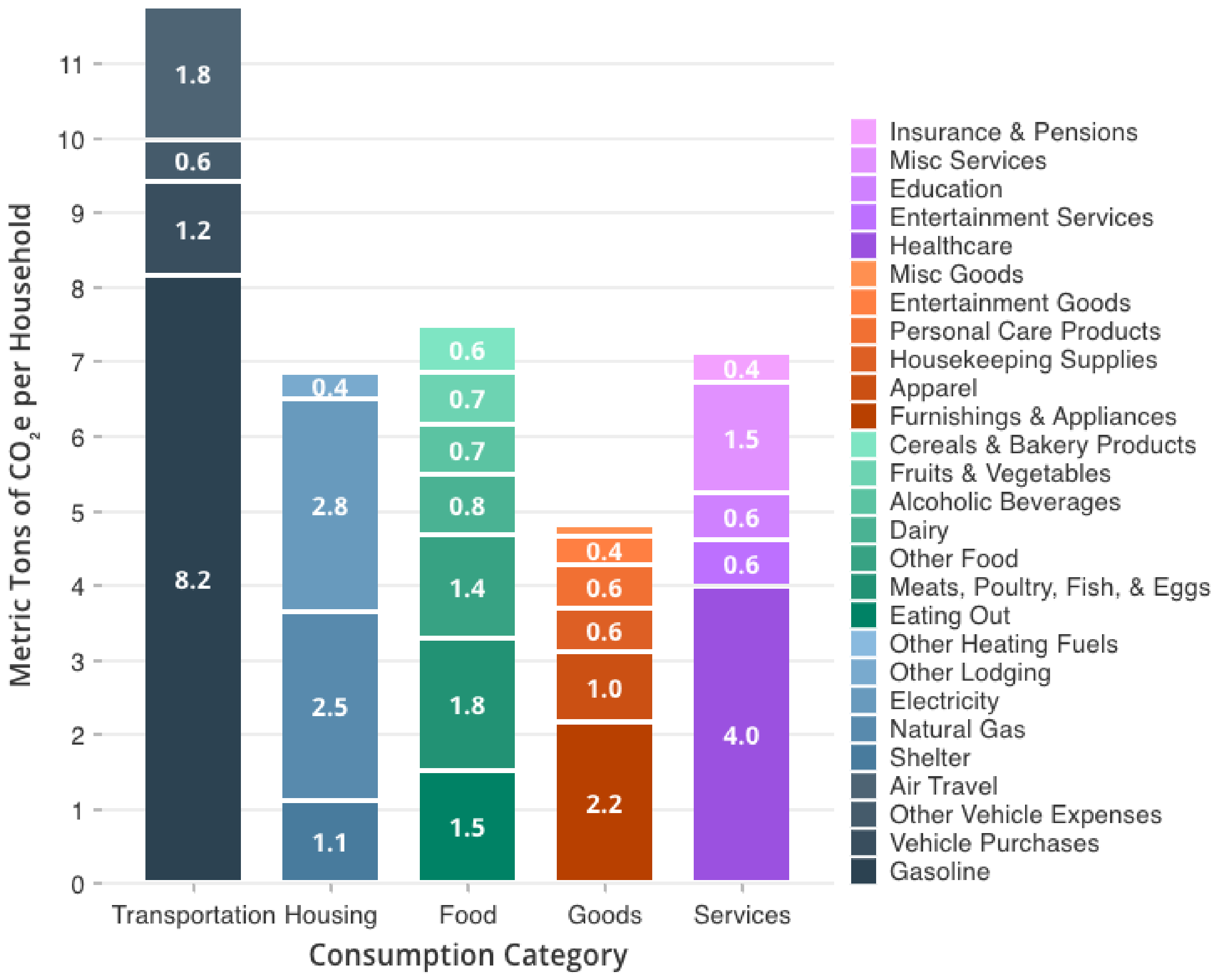
Introduction

A consumption-based emissions inventory (or "CBEI") is an estimate of the greenhouse gas emissions associated with the activity of all residents of a geographic area. It's equivalent to a personal household carbon footprint estimate, except calculated for all households in a jurisdiction. Consumption-based emissions are modeled based on local variables such as income and vehicle ownership, and on scientific studies that tie these variables to changes in consumption-based emissions.

In Boulder in 2021, the typical household was responsible for roughly 38 metric tons of CO_2e annually ($MTCO_2e$), or about 17.5 $MTCO_2e$ per person. With 42,376 households in the city, this is a total of roughly 1.6 million $MTCO_2e$ in 2021 attributable to residents of Boulder.

The bar chart below provides an overview of the city's average per-household emissions in 2021. The actual emissions of any particular household, however, could vary significantly from this average. Differences in household size, spending, housing, travel, and other discretionary and non-discretionary factors will affect any individual household's emissions.

Figure 1. Boulder consumption-based inventory

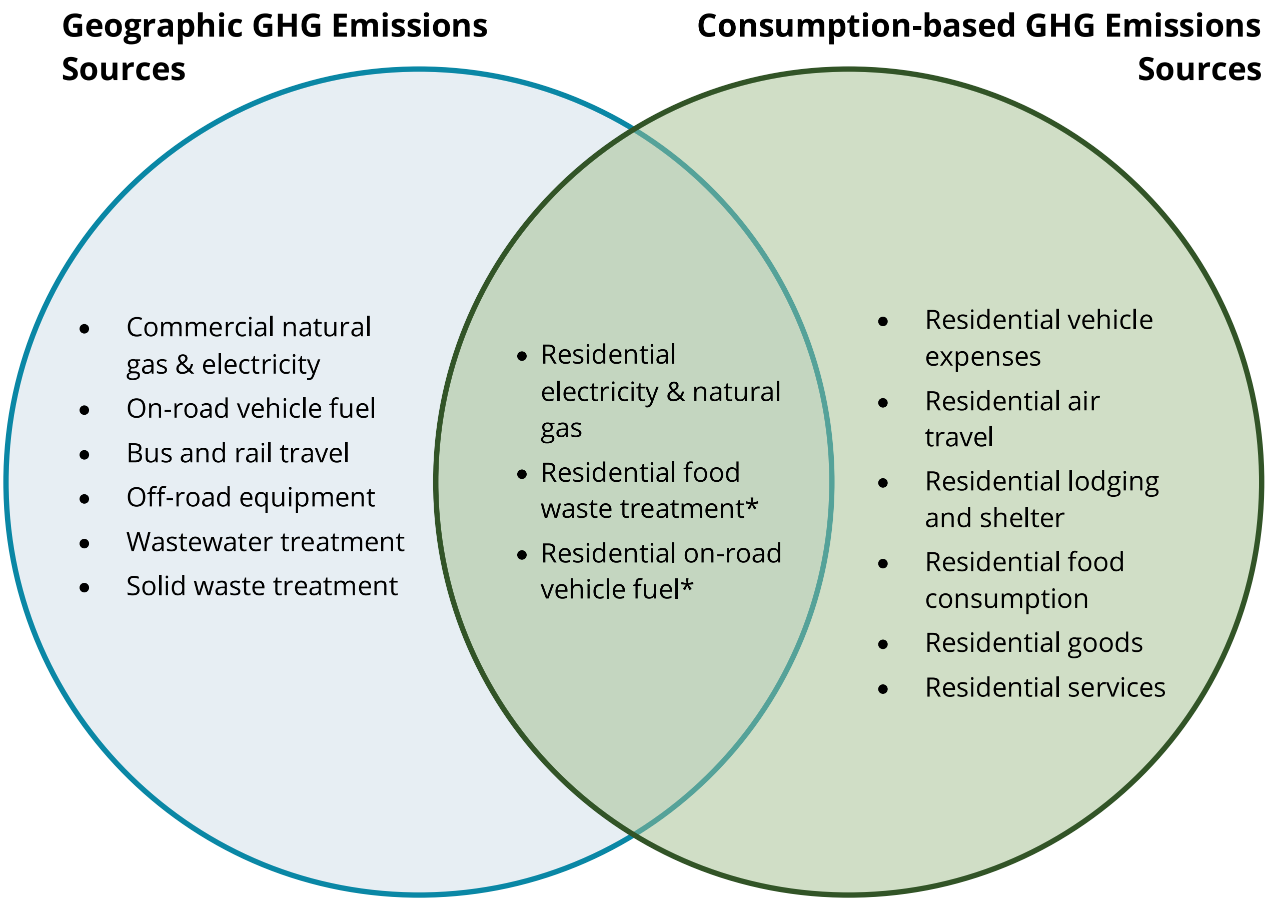


Consumption-Based Emissions Approach

CBEIs differ from traditional greenhouse gas inventories. In traditional sector-based or "geographic" inventories, a city would look at all emissions that occur within the city's borders. In contrast, CBEIs consider emissions that may occur anywhere in the world, as long as they are directly or indirectly a result of the activities of the residents of the city.

Geographic and consumption-based approaches are complementary and partially overlapping. Both will look at resident's local, direct emissions (e.g., from driving or home heating). A geographic inventory will also consider the emissions from local businesses and visitors, but ignore anything outside the city's boundaries. Meanwhile, a consumption-based inventory will omit the local emissions from businesses and visitors, but instead account for emissions associated with resident's travel to other cities, as well as the emissions associated with producing the goods and services they purchase or consume. Those consumption-based emissions may occur anywhere in the world.

Figure 2. Geographic vs. Consumption-Based Emission Sources



*Different methodologies are used to quantify these emissions in each inventory.

These consumption estimates are developed using a model that primarily considers six key household variables:

- household size (people per household),
- household income, vehicle ownership (cars per household),
- home size (rooms per home),
- educational attainment (bachelor's degree or higher for at least one member of the household), and
- home ownership.

These variables often have clear, direct effects on consumption. For instance, larger homes generally take more energy to heat or cool, while more people per household also means more food consumed per household.

The table below compares the values of these variables in Boulder with the US averages as of 2021, using data from the 1-year American Community Survey estimates:

Table 1. Household characteristics, City of Boulder vs. Boulder County vs. United States (2021)

Household Characteristic	City of Boulder Average	Boulder County Average	US Average
Household Income	$112,180	$120,464	$93,667
Vehicle Ownership	1.66	1.88	1.83
Household Size	2.19	2.34	2.60
Home Size (rooms)	5.56	6.45	6.51
Home Ownership	46%	62%	65%
Educational Attainment	72%	65%	38%

The emissions profile for Boulder is based on a average household in 2021, using the overall average household characteristics for Boulder. Most actual households in the city differ in one or more ways. For Boulder, the average household has 2.19 people, living in a 5.56-room home, with 1.66 vehicles and an annual income of $112,180. Households with different characteristics are expected to have different emissions profiles.

Individual households may estimate their carbon footprint by using personal household carbon footprint calculators, such as the one provided by the University of California at Berkeley's CoolClimate Network: https://coolclimate.org/calculator

For a more detailed breakdown of how these and other factors affect emissions, see Appendix A: Methodology.

Major Categories of Consumption-based Emissions and Detailed Breakdown

Among all categories, transportation, food, and services are the largest overall categories, accounting for 31%, 20%, and 19% of emissions, respectively. Together, these account for over 68% of total emissions. Within sub-categories, gasoline, healthcare, and electricity are the top three, accounting for 21%, 10%, and 7% of total emissions, respectively - a combined 39%.

The following sections discuss each category in greater detail, along with further discussions of some specific sub-categories of particular interest.

Transportation

The transportation category includes gasoline usage, vehicle purchases & maintenance, and air travel. For an average household in Boulder, transportation accounts for 11.8 $MTCO_2e$ per year, per household. Much of this comes from gasoline, which accounts for 8.2 $MTCO_2e$, or 69% of the total transportation emissions.

Gasoline

Gasoline consumption is the top source of emissions in Boulder, responsible for 8 $MTCO_2e$ per household. There are two key components that drive gasoline consumption: vehicle ownership and the amount of driving per vehicle.

Nationwide, the US average is about 1.8 vehicles per household[1]. A typical vehicle is driven over 11,000 miles per year[2], and so the average American household drives roughly 20,500 miles per year.

Meanwhile, Boulder households have an average of 1.66 vehicles per household, and drive an estimated 17,025 miles per year. This works out to about 10,256 miles per vehicle, or 91% of average.

Lower vehicle ownership strongly corresponds to lower household vehicle miles traveled (VMT). Vehicle ownership is also substantially driven by place of residence.

[1] 2019 American Community Survey (ACS) 5-Year Estimates: https://data.census.gov/table
[2] Alternative Fuels Data Center (AFDC), https://afdc.energy.gov/data/10309

Boulder residents are remarkably car-free for work: only 38% of workers living in Boulder drove alone to work, with an average commute time of 10 minutes.

Vehicle ownership has not changed substantially after the COVID-19 pandemic – if anything, it increased slightly. Instead, commute modes have shifted dramatically. Prior to COVID-19, roughly 50% of workers drove alone to work; as of 2021, only 38% drove alone to work. Work from home has risen from about 16% to 42%, and average time to work has dropped from 17 minutes to 10 minutes. However, public transit, carpooling, walking, and biking has also declined. Public transit dropped the most precipitously: from roughly 9% of workers in 2019 to just 2% in 2021; carpooling fell from 7% to 4%; and walking declined from 8% to 6%. Biking saw only a small change, dropping from 10% to 9%.

Air Travel

For many individual households, air travel is a significant portion of emissions. However, for Boulder overall, air travel is only a small part of the city's consumption-based emissions, coming in at 1.8 $MTCO_2e$ per household on average (4.7% of total emissions). This varies significantly between households, however, largely due to income: air travel is a luxury for most households, and only the wealthiest households do substantial flying.

According to Gallup survey data, between 1999 and 2015, 48-60% of the US population did not fly in any given year[3]. More recent data from Statista.com suggests that in 2019, 41% of the US population 18 and up had never traveled by air, and another 28% flew only about once per year[4].

Air travel in a mostly full aircraft is more fuel efficient than driving alone, but the high-altitude pollution released is uniquely damaging to the environment and can make flying worse than driving. Most modern aircraft get roughly 70-100 miles per gallon per passenger seat[5], with fuel economy improving for longer flights. In comparison, the average fuel economy for new vehicles nationwide was 25.4 miles per gallon in 2020[6]. However, due to additional climate effects from high-altitude particulate matter, as well as lifecycle production of aviation fuels, air travel's

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[3] Gallup, Airlines: https://news.gallup.com/poll/1579/airlines.aspx
[4] Statista, Air travel frequency in the United States in 2019: https://www.statista.com/statistics/539473/airline-travelers-number-of-trips/
[5] Wikipedia, Fuel Economy in Aircraft: https://en.wikipedia.org/wiki/Fuel_economy_in_aircraft#Regional_flights
[6] Environmental Protection Agency, Highlights of the Automotive Trends Report: https://www.epa.gov/automotive-trends/highlights-automotive-trends-report

overall emissions are roughly double what would be expected on a per gallon basis alone, making it more like driving a 35-50 miles per gallon car. As a result, air travel may be more fuel-efficient than driving alone in an average vehicle, but usually not for two or more individuals traveling together, or for a single individual in a very efficient or all-electric vehicle. Very short flights (less than 300 miles) typically have extremely poor fuel economy, and may not be more fuel efficient than driving alone in an average vehicle.

Air travel often results in significant emissions due to the long distances traveled.

Housing

Household energy use, home construction and maintenance (shelter), water, and waste make up the Housing category. Overall, a typical Boulder household has 7 $MTCO_2e$ resulting from housing, with the largest single category being electricity. Electricity produces 2.8 $MTCO_2e$, or 40% of the total housing emissions.

Electricity

Boulder's electricity emissions derive from Xcel Energy data showing an average electricity usage of about 5,951 kWh per household, with an emission factor of roughly 477 grams of CO_2e per kWh, resulting in about 2.8 $MTCO_2e$ of emissions per year per household. Due to heavy coal usage for electricity generation, these emissions are much higher than the US national average.

Roughly 36% of households in Boulder use electricity for heating.

Natural Gas

Natural gas is a common fuel for home heating, water heating, clothes drying, and cooking. The primary ingredient of natural gas is methane (CH_4), a potent greenhouse gas. Most GHG emissions associated with natural gas result from burning the gas to produce heat, which also emits carbon dioxide (CO_2). In addition, some methane is leaked into the atmosphere during the extraction, processing, and transport (piping) of natural gas into homes.

Burning natural gas in homes not only contributes to CO_2 emissions, but it also contributes to local indoor and outdoor air pollution. Natural gas combustion produces carbon monoxide, nitrogen dioxide, fine particulate matter ($PM_{2.5}$), and formaldehyde, among other pollutants[7]. When burned in furnaces for heating or water heating, these fumes are vented into the surrounding neighborhood, where they generally disperse at low concentrations. When burned in a gas stove or oven, these fumes are emitted directly into residential living spaces, which are often not adequately vented. As a result, gas stoves can lead to dangerously elevated levels of indoor air pollution[8]. Even moderately well-ventilated homes with gas stoves can have elevated levels of air pollutants that have increase the risk of asthma in children and exacerbate asthmatic symptoms in adults[9].

Methane extraction, transport, storage, and distribution systems nationwide typically have small leaks. Methane itself is a much more potent greenhouse gas than CO_2. One ton of methane has the same warming impact as nearly 30 tons of CO_2 when considered over a 100-year time frame, and 80-90 tons of CO_2e when considered over a 20-year time frame. As a result, if even just 5% of methane is lost to leaks, it would mean that the leaked methane is a bigger contributor to climate change than the CO_2 from burning the other 95%. In 2021, emissions from natural gas leakage were estimated to increase overall emissions from natural gas by about 14%[10].

Nationally, the Environmental Protection Agency (EPA) estimates about half of all methane leaks occur in production, with another 25% occurring in transmission and storage[10]. Distribution and post-meter leakage each contribute about 10% to the overall leakage rate.

Natural gas usage for Boulder is roughly 421 therms per household, resulting in 2.5 $MTCO_2e$. About 61% of households in the city use gas for heating.

Water

The average household in Boulder uses an estimated 45,864 gallons per year. With an estimated emissions factor of 3.2 grams of CO_2e per gallon, the average household has roughly 0.15 $MTCO_2e$ associated with their water use. As a result,

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[7] California Air Resources Board, “Combustion Pollutants & Indoor Air Quality” https://ww2.arb.ca.gov/resources/documents/combustion-pollutants-indoor-air-quality
[8] Rocky Mountain Institute, “Gas Stoves: Health and Air Quality Impacts and Solutions” https://rmi.org/insight/gas-stoves-pollution-health/
[9] American Journal of Respiratory and Critical Care Medicine, “Indoor air pollution and asthma. Results from a panel study.” https://www.atsjournals.org/doi/abs/10.1164/ajrccm.149.6.8004290
[10] US EPA, “Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019” https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2019

water consumption is not a significant contributor to consumption-based emissions.

Food

The Food category includes all food consumed by residents of Boulder, broken down by meat, dairy, fruits & vegetables, and other foods consumed at home, as well as eating out. Food accounts for 7.5 $MTCO_2e$, and the single largest sub-category is meats, poultry, fish, and eggs at 1.8 $MTCO_2e$, or 24% of total food emissions.

Globally, roughly 24% of greenhouse gas emissions are a result of agriculture, forestry, and other land use changes, with the majority of these emissions resulting from agriculture. In the US, agriculture resulted in roughly 623 million $MTCO_2e$ in 2019, or about 10% of national emissions (according to the US EPA's most recent national inventory[10]).

Emissions from agriculture are driven primarily by two sources. In the US, most agricultural emissions derive from nitrous oxide (N_2O), a greenhouse gas that is released from the breakdown of nitrogen-based fertilizers. N_2O accounts for roughly 55% of US agricultural greenhouse gas emissions.

The second-largest source of agricultural emissions is methane (CH_4), a potent greenhouse gas which is produced by certain animals like cows, sheep, and goats. These animals rely on microbes to break down the grass and other plants they eat, in a process known as enteric (intestinal) fermentation. This digestive fermentation produces methane as a byproduct, much in the same way that beer fermentation produces CO_2 as a byproduct. Methane from digestion accounts for nearly 30% of the US GHG emissions from agriculture[10]. The decomposition of animal manure (also into methane) contributes another 12% of agriculture emissions[10]. Nitrous oxide and methane combined account for 97% of emissions directly associated with agriculture[10].

The consumption-based emissions inventory includes these direct nitrous oxide and methane emissions from agriculture, emissions from fixed capital investments in agricultural equipment and facilities, as well as emissions associated with transport and sale of food. In the consumption-based emissions inventory, direct emissions from agriculture are the majority of the emissions associate with food. Generally around 67-80% of food emissions come directly from food production (see C: Emissions Breakdown by Supply Chain Stage). For most foods, transportation comprises about 5% of the emissions, while wholesale and retail make up another 5-15%. Typically, fixed capital investments (e.g. buildings and equipment) is estimated around 13% of total emissions.

While N_2O from nitrogen fertilizer is the single largest source of agricultural emissions nationally, meat & dairy are often the largest sources of at-home food emissions for households. In Boulder, meat, poultry, fish, eggs, and dairy combined account for 2.6 $MTCO_2e$ of emissions, while fruits & vegetables, cereals, and other foods account for 2.7 $MTCO_2e$.

Despite being only a small fraction of overall calories consumed, meat & dairy have an outsized impact on the typical household's emissions associated with food. This is because the emissions associated with meat consumption not only includes the direct methane emissions from the animals, it also includes the nitrous oxide emissions from growing all of the crops to feed those animals.

It takes a lot of feed crop, mostly corn[11], to produce one calorie of meat. In the case of beef, it can be as many as 33 calories of feed per calorie of beef[12]. As a result, a quarter pound of beef (284 calories) could require over 9,000 calories of corn to produce.

Further compounding these food emissions is the fact that an estimated 30-40% of food goes to waste[13]. Emissions from the production of wasted food is included in the overall emissions associated with food, driving up the emissions of all food consumption. While some of this loss occurs in production, storage, or transport, households are often also a significant source of food waste. According to the United Nations, US households purchase more calories per capita than any other country - nearly 3,800 calories per person per day in 2018[14]. This includes all purchased food, whether consumed or otherwise.

Eating out, such as at restaurants, also contributes to a portion of food emissions. For the typical Boulder household, eating out is associated with roughly 1.5 $MTCO_2e$ per year. However, this includes not only all the food consumed while eating out, but also the operational emissions from restaurants, including emissions from cooking, transportation, and construction of the building. In comparison, household

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[11] US Department of Agriculture, "Feedgrains Sector at a Glance" https://www.ers.usda.gov/topics/crops/corn-and-other-feedgrains/feedgrains-sector-at-a-glance/
[12] A Shepon et al 2016 *Environ. Res. Lett.* **11** 105002 https://iopscience.iop.org/article/10.1088/1748-9326/11/10/105002/pdf
[13] US Department of Agriculture, "Food Waste FAQs" https://www.usda.gov/foodwaste/faqs
[14] United Nations Our World in Data, "Food Supply" https://ourworldindata.org/food-supply

emissions from cooking, transportation, and construction are allocated to the transportation and housing sectors. Overall, eating out likely has similar emissions per calorie as food prepared at home; however, restaurants across the US often also serve much larger portions than are typically consumed at home, which can lead to further food waste or excess.

Goods

Goods includes all physical items purchased by households (excluding items in other categories, like food & fuel). Goods includes things like furniture, personal electronics, clothing, toys, and books. These goods account for 4.8 $MTCO_2e$ per household per year. Of these goods, furnishings & appliances is the single largest source, making up 2.2 $MTCO_2e$, or 45%, of total goods.

Generally, goods have lower emissions per dollar than food or energy. Households with higher incomes tend to spend more money (as well as a greater fraction of their income) on these various goods and services. Homeowners also tend to spend more on home furnishings and equipment.

In Boulder, the largest sources of emissions from goods comes from household furnishings and equipment (including miscellaneous household equipment, furniture, and appliances), as well as apparel (clothing).

Services

Services includes the emissions associated with things like healthcare, education, insurance & finance, and entertainment experiences like concerts and museums. Services account for 7.1 $MTCO_2e$ per household, and the single largest category is healthcare at 4 $MTCO_2e$, or 56%.

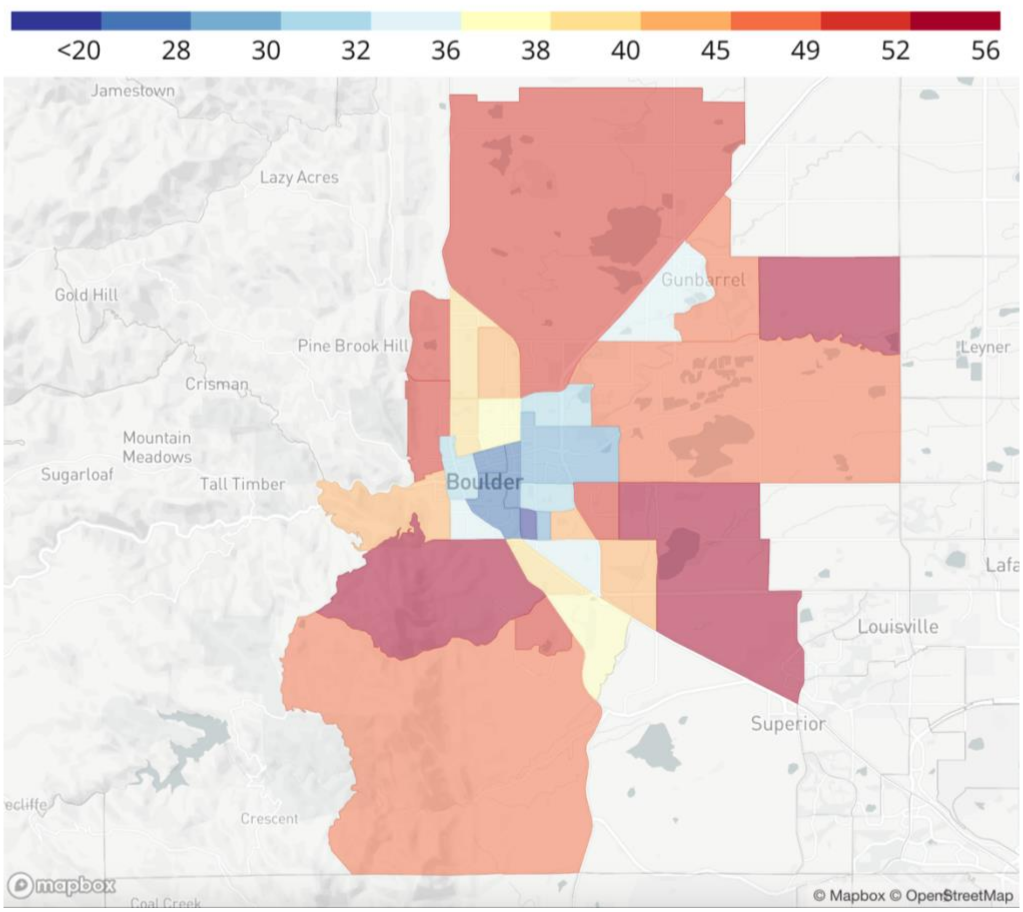
Healthcare dominates emissions from services primarily because it is a large economic sector. Nationally, healthcare makes up roughly 18% of the US economy; in Boulder, healthcare emissions are about 10% of the average household's carbon footprint. Healthcare emissions include emissions from the construction and operation of hospitals, doctor’s offices, and other medical facilities; manufacturing of pharmaceuticals and medical equipment; and more.

Other major categories of emissions include entertainment services (mostly fees & admissions to museums, concerts, etc.), education, financial services like insurance & pensions, and miscellaneous services (including personal care, household operations, etc.). These are generally smaller categories because average households spend much less on these other services. However, households with an adult who has a college degree tend to spend more on entertainment services, financial services, personal care products & services, and education. Boulder is a very highly educated community, but because of its other household characteristics (such as smaller household size), it still has lower emissions per household from services than the US average.

Neighborhood Variation

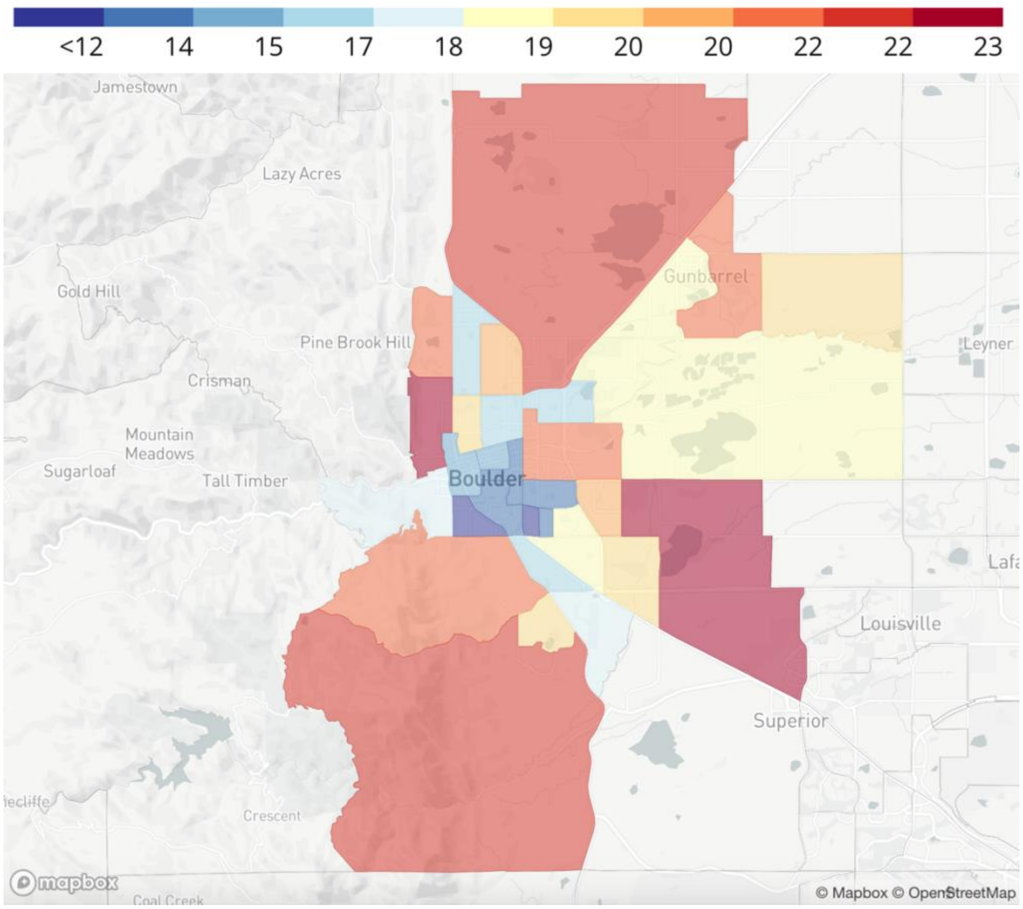
Among the 32 neighborhoods (census tracts) within the city, there is substantial variation in both emissions and the key driving variables. The highest-emitting neighborhood has per-household emissions of 56 $MTCO_2e$, while households in the lowest-emitting neighborhood have emissions of 26 $MTCO_2e$ - roughly a 2-fold difference, as shown in Figure 3.

Figure 3. Consumption-based emissions map ($MTCO_2e$ per household)



On a per-capita basis, these differences are similarly pronounced. Boulder's highest per-capita neighborhoods have emissions of 23 $MTCO_2e$, while households in the lowest-emitting neighborhood have emissions of 12 $MTCO_2e$ - roughly a 2-fold difference, as shown in Figure 4.

Figure 4. Consumption-based emissions map ($MTCO_2e$ per person)



The variation in emissions between neighborhoods is driven by a wide range of factors.

The following maps show how the six core household characteristics:

- income,
- household size,
- vehicle ownership,
- home size (number of rooms),
- home ownership, and
- education

vary across the city, with subsequent implications for consumption-based emissions.

Figure 5. Boulder Average Household Income Map

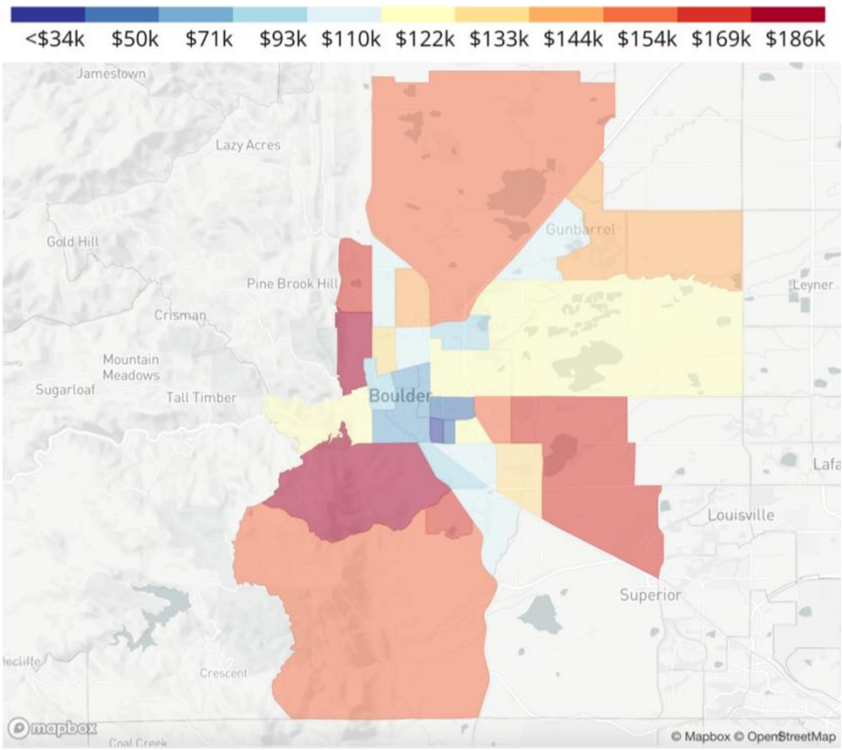


Figure 6. Boulder Household Size Map

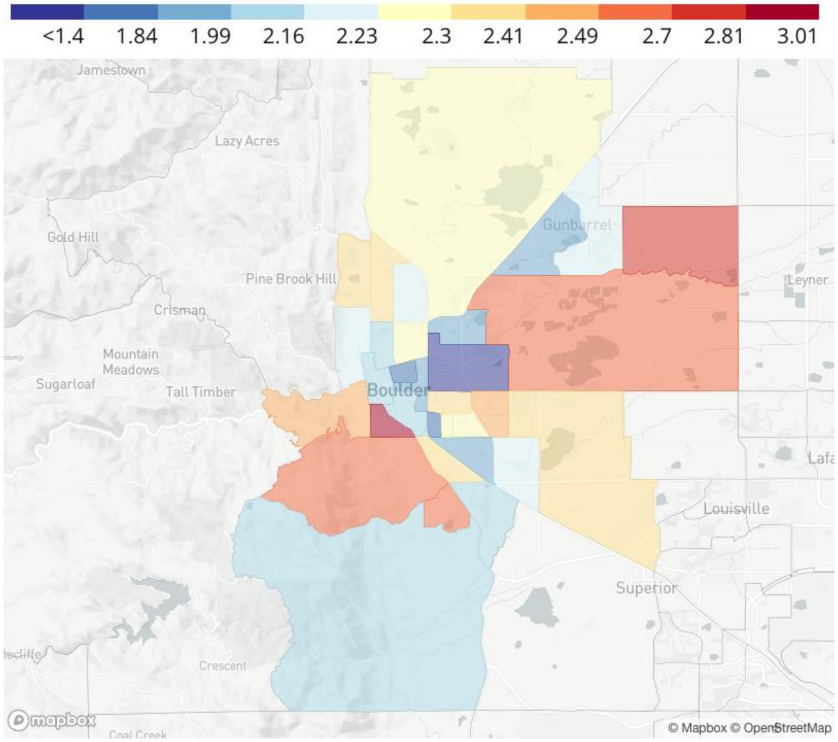


Figure 7. Boulder Vehicle Ownership Map

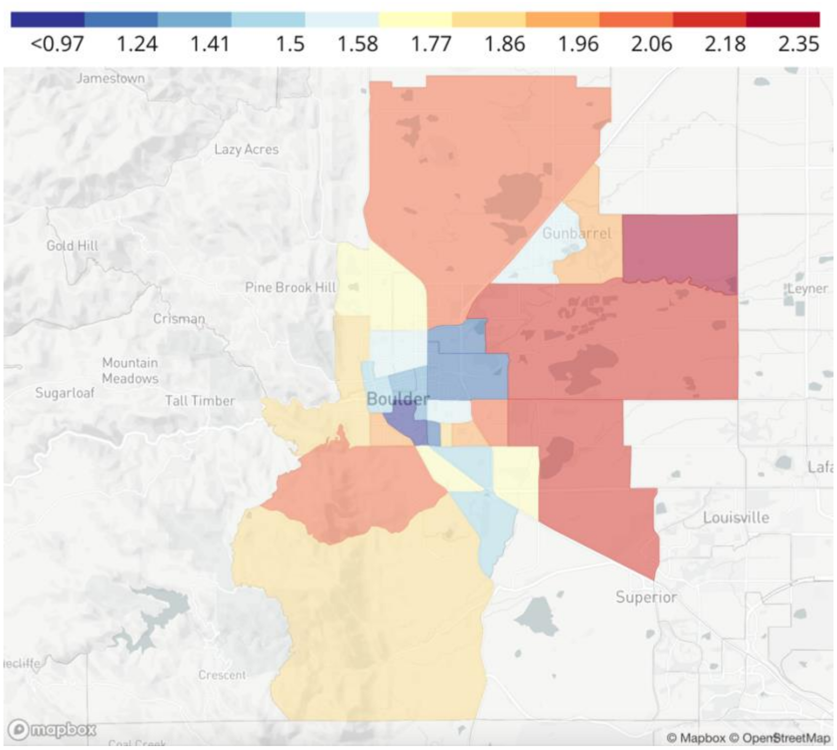


Figure 8. Boulder Rooms per Household Map

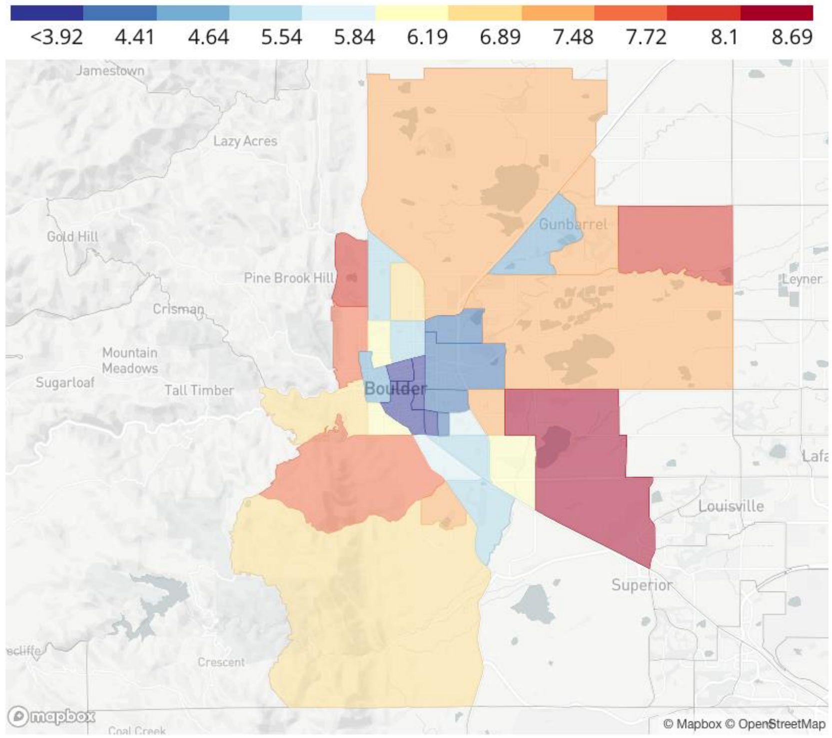


Figure 9. Boulder Home Ownership Map

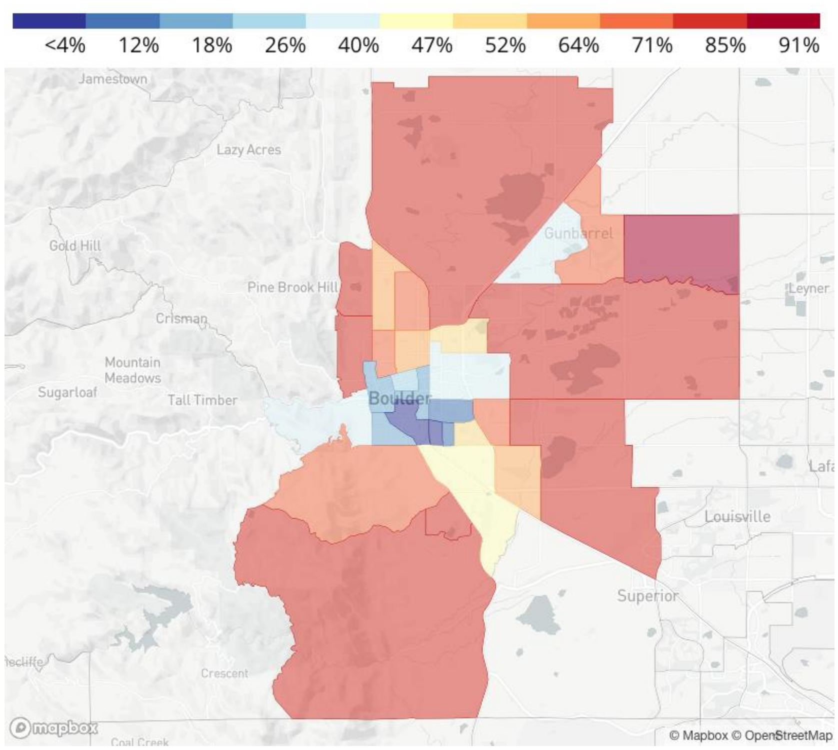
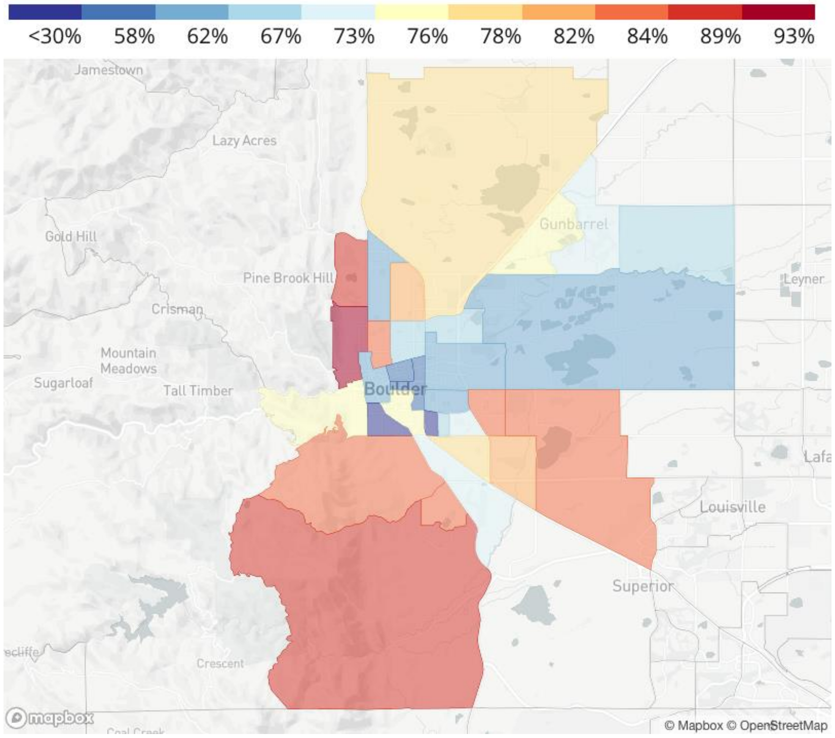


Figure 10. Boulder College Degree Attainment Map



The variation in emissions between neighborhoods is driven by a wide range of factors, and the history of local land use planning is a significant influence on the consumption-based emissions. Local jurisdictions adopt plans and regulations specifying what kinds of buildings can be built, under what conditions, and to what criteria. This has significant effects on where people choose to live, and what kind of lifestyles can be accommodated, with consequences for consumption-based emissions.

For instance, across the US, major city centers tend to have the lowest emissions per household. The land use plans and historical development in city centers have typically resulted in taller buildings, closer together, often with smaller homes which are typically available for rent. Because more people and destinations are closer together, city centers are often more walkable and have more public transit available, reducing vehicle ownership. Apartments mean lower home ownership; and smaller homes also means households tend to be smaller. Multi-unit dwellings also require substantially less energy to heat and cool each home. Smaller households living in smaller homes are also more likely to be younger, and to not earn as much as older generations, resulting in somewhat lower household income as well.

In contrast, low-density neighborhoods tend to have among the highest emissions per household. These land use plans often encourage large, detached, single-family homes, with spacious yards and setbacks. Larger detached homes take more energy to heat or cool, and the extra space (and lack of nearby destinations) generally results in greater automobile usage. Larger homes also tend to be more expensive, making these neighborhoods exclusive to wealthier households. Households that are drawn to detached single-family homes are also often looking to use the space to raise families, meaning larger household sizes.

In Boulder, the historic downtown core and neighboring areas around CU Boulder are the type of dense, walkable neighborhoods that enable car-free lifestyles – between 10-30% of households in these neighborhoods do not own a car. However, the average vehicles per household is still relatively high. While immediate destinations may be accessible without a vehicle, many places to shop, dine, or otherwise visit elsewhere in the city, in the county, and beyond are only accessible with a car.

The following charts provide some examples of how these neighborhood characteristics correlate with per household emissions across the city.

Figure 11, below, shows census tracts in the city by average household income (horizontal axis) versus household carbon footprint (vertical axis). Each dot represents a census tract (neighborhood). Higher incomes strongly correspond to greater consumption emissions. There is little variation between census tracts at a given income level. While greater disparities between emissions at a given income level can happen in some cities with expensive but walkable neighborhoods, these data suggest Boulder's middle- and high-income neighborhoods are not conducive to reduced automobile use. Boulder's lowest income (and lowest emission) tracts are student-heavy neighborhoods close to CU Boulder.

Figure 11. Household income vs. emissions

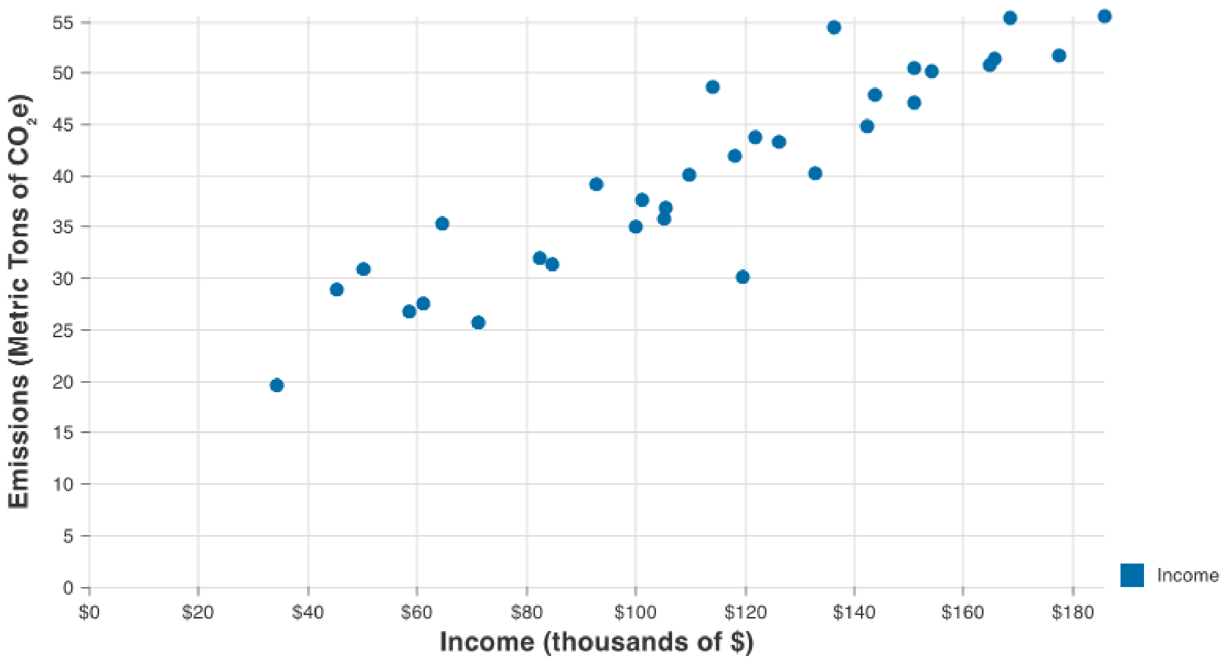


Figure 12 shows census tracts in the city by number of vehicles owned (horizontal axis) versus household carbon footprint (vertical axis). Each dot represents a census tract (neighborhood). Greater vehicle ownership strongly corresponds to greater emissions, almost entirely due to the increased driving associated with the extra vehicle(s). Boulder's wealthiest households also tend to own extra vehicles, though they may not be used as much. Only one census tract has fewer that 1 vehicle per household – a student-heavy neighborhood adjacent to CU Boulder.

Figure 12. Vehicle ownership vs emissions

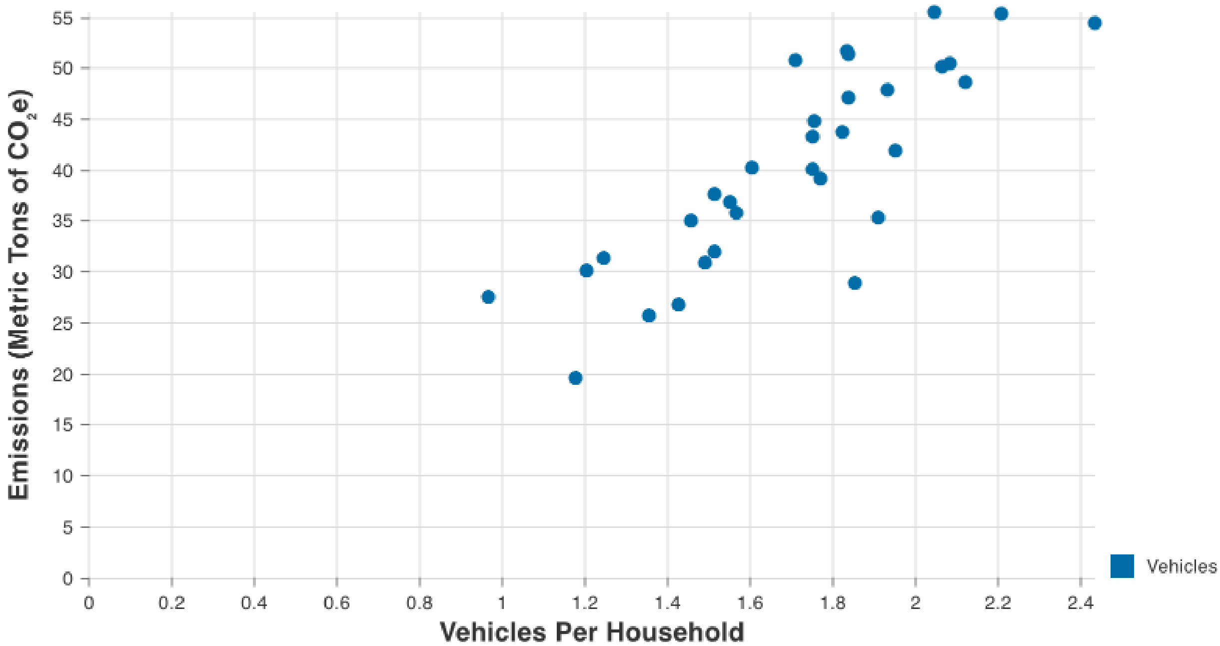


Figure 13 shows census tracts in the city by number of rooms per home (horizontal axis) versus household carbon footprint (vertical axis). Each dot represents a census tract (neighborhood). More rooms per home strongly corresponds to greater emissions - homes with more rooms take more energy and associated emissions to heat or cool and have more space to accommodate more purchases of furniture and other household goods. Boulder's highest-emission tracts are comprised of large, expensive homes.

Figure 13. Rooms vs emissions

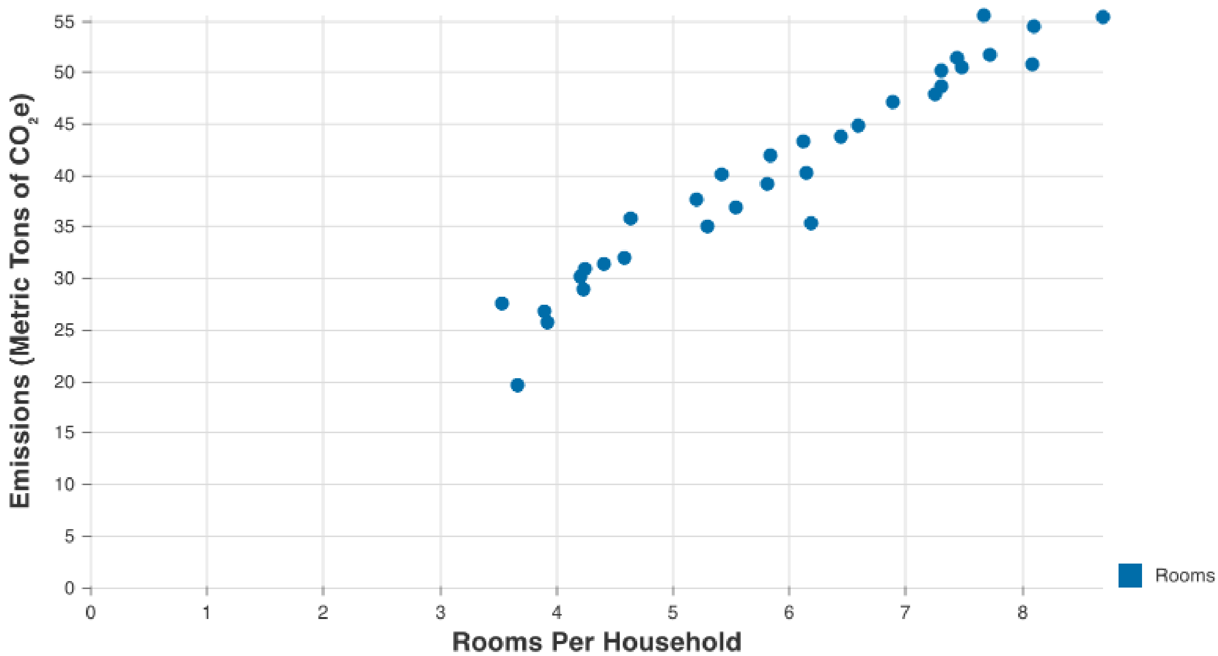


Figure 14 shows census tracts in the city by percent of households which own their home (horizontal axis) versus household carbon footprint (vertical axis). Each dot represents a census tract (neighborhood). Greater home ownership strongly corresponds to greater emissions. This is partly because home ownership correlates with income and household size. It is also because home ownership on its own leads to more consumption of goods that are higher emissions. For instance, this may include furniture and miscellaneous housewares. Boulder's lowest-emitting tracts, as mentioned, are student-heavy neighborhoods near CU Boulder, which are almost entirely comprised of renters; meanwhile, the wealthy neighborhoods that comprise its highest-emitting tracts are virtually all homeowners.

Figure 14. Home ownership vs. emissions

Historical Trends

Data for the consumption-based emissions inventory spans back to 2007. For this analysis, the full range of historical trends is used. Since 2007, per household $MTCO_2e$ emissions have changed by -14.2%, or -6.3 $MTCO_2e$ per household, as show in the chart and table below.

Figure 15. Historical CBEI trends

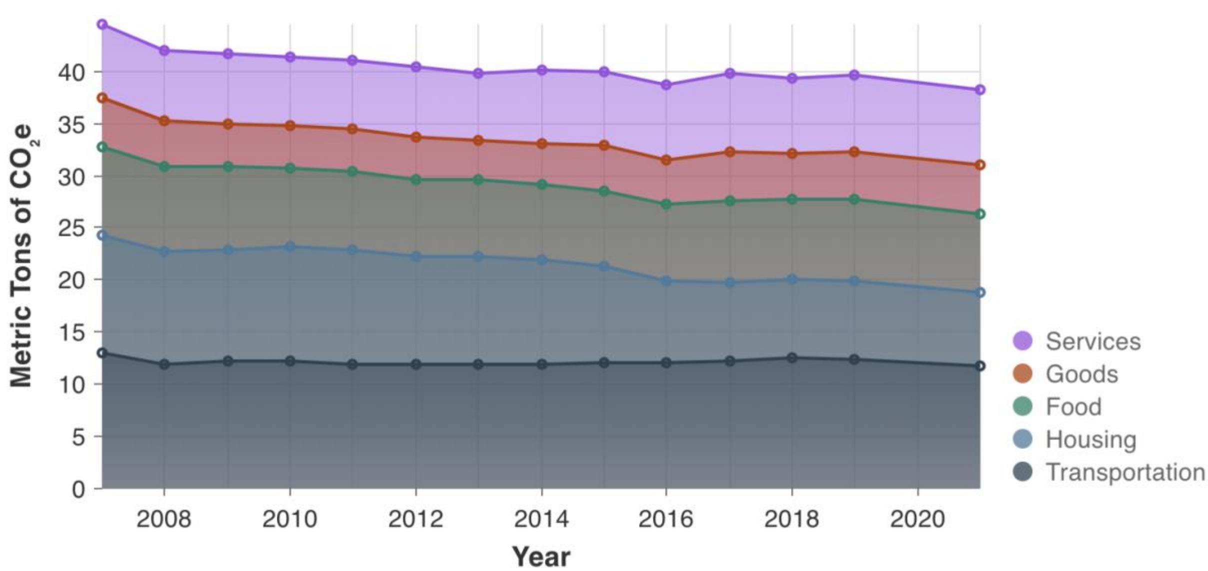


Table 2, below, compares emissions in 2007 and in 2021 on a per household basis (unless otherwise stated). Services and Goods have seen the largest increases, each of 2% and 1%, respectively, while housing and food have seen the greatest declines, of -62% and -14%.

Table 2. Boulder Changes in Emissions Over Time (2007-2021)

Emissions Category	Boulder (2007)	Boulder (2021)	% Change
Total Emissions	44.6	38.2	-14.2%
Transportation Emissions	12.9	11.8	-8.8%
Housing Emissions	11.4	7	-38.1%
Food Emissions	8.5	7.5	-12.3%
Goods Emissions	4.7	4.8	2.2%
Services Emissions	7	7.1	1.2%
Total Per Capita Emissions	19.9	17.5	-12.3%

At a national level, the carbon intensity of goods and services has been declining. The electricity grid has been getting cleaner, vehicle fuel economy has been improving, and industries have generally been figuring out how to produce more with less emissions. In particular, Boulder has seen greater than average declines in emissions from electricity, as coal use has declined substantially. Emissions from food have also declined, though this is predominantly due to national improvements in farming efficiency and reduced emissions per dollar of produce. Lastly, transportation emissions have declined as vehicle fuel economy has improved nationally; vehicle miles traveled (VMT) has remained largely constant.

Boulder has seen moderate demographic changes over this period. Since 2007, household incomes have increased by over $35,000, or 45%. After adjusting for inflation, this is an increase of 12%. The share of households with a college degree remained grew significantly since the Great Recession: while in 2007 69% of households held a bachelor’s degree or higher, that number dropped to 62% in 2008. By 2021, it was 72%. Meanwhile, vehicle ownership, home size, household size, and home ownership rates have remained largely flat.

Figure 16. Income over time

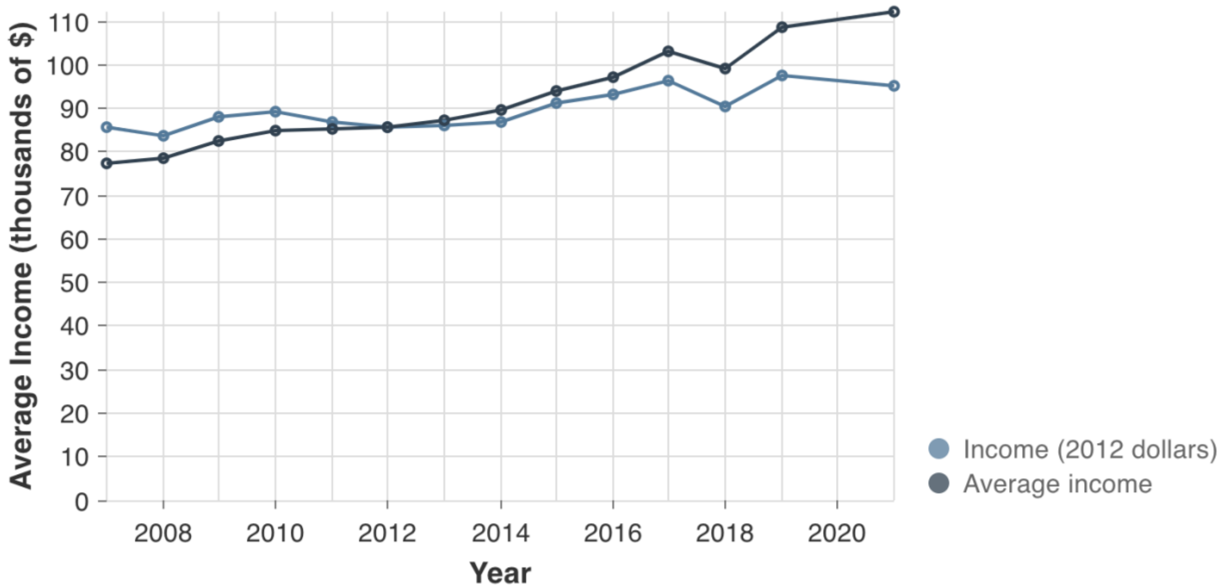


Figure 17. Percent with college degree and homeownership rate trends

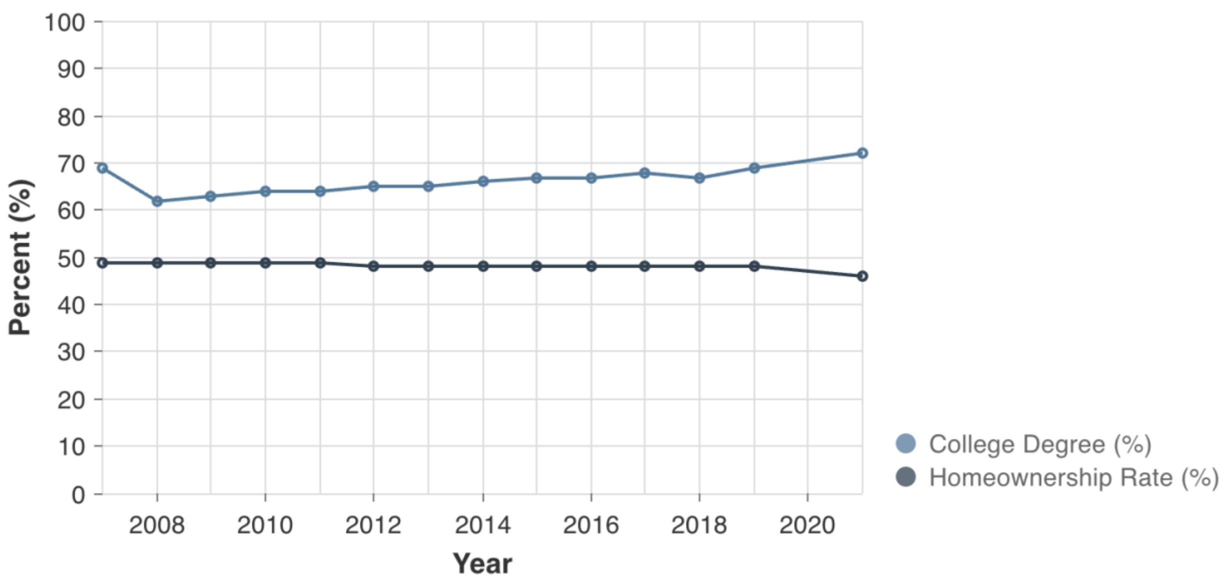
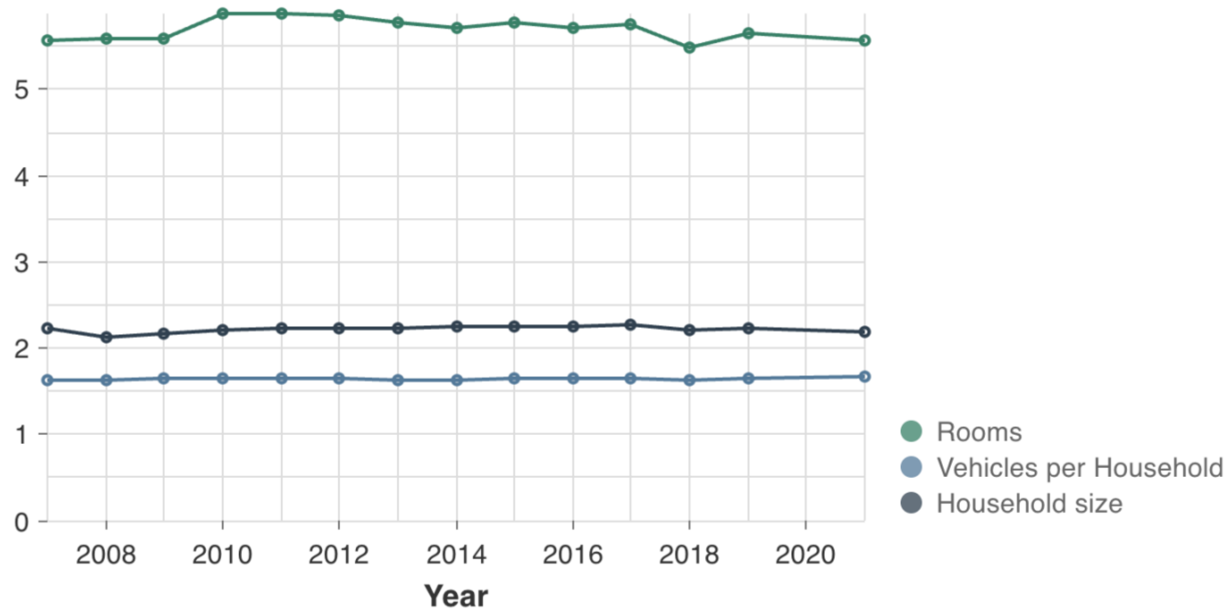


Figure 18. Rooms, vehicles per household, and household size trends over time



Discussion

Boulder has a number of opportunities to address consumption-based emissions. In particular, three sub-categories of consumption-based emissions have close overlap with existing climate action efforts: electricity, natural gas, and gasoline (driving).

Like many jurisdictions, Boulder must also find ways to phase out the use of natural gas for space and water heating and retrofit homes with all-electric heat pumps and induction cooktops. However, at the same time, the city's available electricity suppliers currently rely heavily on exceptionally dirty coal power. Boulder needs to simultaneously decarbonize its electricity supply while advancing building electrification.

Boulder also needs to address transportation emissions. While most of the communities in the county will need to focus on electric vehicles, Boulder is already the most walkable and bikeable community in the county, with a strong foundation in infrastructure and transit service. However, these modes still have many opportunities for improvement, as evidenced by the city's level of automobile ownership and usage. Boulder can build upon this by allowing more housing close to walkable and bikeable destinations, and by fully implementing existing plans to expand transit, walking, and biking infrastructure.

Energy & Buildings

Renewable Energy

At present, the City's efforts on renewable energy primarily focus on rooftop and community solar. These are important efforts that should be maintained, and partnerships with the County can be leveraged to advance this. If it wanted to go further, Boulder could likely explore opportunities to create a community choice energy program, whether directly managed by the City or in collaboration with local jurisdictions, to seek out and purchase greater levels of renewable energy than currently offered by Xcel Energy.

Natural Gas

Natural gas use in homes is a larger share of emissions in the CBEI than electricity. As Boulder develops more renewable energy and Xcel moves towards its goal of 80% renewable by 2030, this share of emissions coming from natural gas will continue to grow.

The only long-term effective strategy for eliminating natural gas emissions is to electrify buildings – replacing hot water heaters and furnaces with heat pumps, switching to electric clothes dryers, and phasing out gas stoves for induction. Replacing these gas appliances with electric options will improve energy efficiency overall – heat pumps are often 200-300% efficient, or more – but even at an average 250% efficiency, with 421 therms of natural gas usage, the average household is likely to increase its electricity use by over 80% from building electrification alone, not including the additional electricity required for an electric vehicle. As a result, while electrification is critical, Boulder will struggle to realize significant emissions reductions if it does not simultaneously meet its renewable energy needs.

Transportation & Land Use

Boulder has a historic downtown and adjacent neighborhoods that predate World War II, built around streetcar lines and generally walkable. However, subsequent development in Boulder built out car-centric neighborhoods and moved businesses into office parks and malls, further from the urban core. The more historic, compact neighborhoods by and large have not been zoned for multifamily housing, leaving new development to sprawl into former agricultural areas and natural habitats.

Land Use

Historical land use decisions play a major role in shaping consumption-based emissions. Land use policies determine the characteristics of the local housing stock, and influence core household characteristics like home size, home ownership, household size, household income, and vehicle ownership. Zoning regulations which ban apartments and townhomes tend to result in larger homes, more automobile dependency, and higher housing costs.

Neighborhood-level analyses of consumption-based emissions across the United States shows that dense, walkable communities tend to have lower emissions per household than car-dependent, lower-density neighborhoods[15,16]. This finding holds true even in areas where incomes are very high (such as New York City and San Francisco), as multifamily and mixed-use developments bring significant reductions in emissions from transportation that more than offset the higher incomes in these areas.

Boulder is working to encourage and enable greater density in its most walkable and bikeable areas. Strategies for enabling more sustainable building types at a range of incomes include:

- Adoption of form-based zoning codes, which regulate the size and shapes of buildings without limiting the number of individual units. This can allow for multi-family building types that resemble single-family buildings (such as duplexes, triplexes, and quadplexes, as well as accessory dwelling units),
- Zoning for buildings up to 6-8 stories[17] in city centers and close to transit,
- Density bonuses and incentives for on-site affordable housing units, or development fees to fund non-profit affordable housing,
- By-right, ministerial, or "over-the-counter" approval, where projects that comply with objective and predetermined zoning standards are approved by staff without further public process, and

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[15] Jones, CM and Kammen, DM. "Spatial Distribution of U.S. Household Carbon Footprints Reveals Suburbanization Undermines Greenhouse Gas Benefits of Urban Population Density" https://pubs.acs.org/doi/abs/10.1021/es4034364

[16] The New York Times, "The Climate Impact of Your Neighborhood, Mapped" https://www.nytimes.com/interactive/2022/12/13/climate/climate-footprint-map-neighborhood.html

[17] 6-8 stories is due to building construction technologies: building codes typically allow for up to 5 stories of wood frame construction above a 1-3 story concrete podium. Beyond 8 stories, construction technologies switch to either steel frame or mass timber; steel frame has higher fixed costs and often requires substantially higher building heights (10-12+ stories) to be economical, while mass timber is a newer technology that is still being adopted by jurisdictions and developers.

- Review of other existing regulations on development standards and fees to ensure adequate profitability remains to drive private-sector development.

In addition, there may be opportunities to change commercial zoning districts to allow for mixed-use, or to zone for mixed-use commercial close to some otherwise exclusively residential suburban neighborhoods. The benefits of density are generally self-reinforcing, and emissions reductions can best be achieved by focusing additional density where demand for it is highest.

Alternative Transportation

Boulder has a substantial bicycle network in place, although many areas are still in need of infrastructure improvements to enhance safety for cyclists and reduce the danger and stress of biking. The City's Low-Stress Walk and Bike Network Plan envisions a comprehensive network of low-stress routes and, if fully implemented, would likely significantly increase biking, with most areas of the city being readily and safely accessible by bike. Similarly, Boulder's Transportation Master Plan includes a number of key initiatives that will substantially improve transit, including improved frequencies, high-quality BRT, improved regional connectivity, and shelter and station improvements.

Electric Vehicles

Significant work is currently being done at the county level to advance electric vehicles. Currently, Boulder County's Climate Action Plan and Sustainability, Climate Action, and Resilience Plan include several strategies to advance EV uptake, including incentives for EV purchases and charging infrastructure, programs to encourage and educate the public on EV adoption, and installation of public chargers at County-owned facilities. The County is also exploring requiring EV chargers in new developments, strengthening subsidies for low-income households, and converting the County's own fleet to EVs.

The City should work to ensure it is in alignment and supporting these county-wide efforts. Because most households in Boulder do not own their own home, a robust public charging network will likely be necessary for many households to switch to EVs.

Conclusion & Next Steps

Boulder's per-household consumption-based emissions are roughly 38 $MTCO_2e$, below the national average of 41 $MTCO_2e$ and well below the countywide average of 43 $MTCO_2e$. This is predominantly due to lower emissions from transportation, electricity, natural gas, and healthcare, in part due to the city's lower vehicle ownership, smaller home sizes, and smaller household sizes.

Boulder has opportunities for new "missing middle", infill, and mixed-use housing close to walkable and bikeable destinations to help add to the diversity of housing options in the city and reduce the average household's consumption-based emissions. In addition, existing efforts around increasing the use of renewable energy, expanding building electrification, and improving biking and transit will help further reduce residents' consumption-based emissions.

Boulder is well-positioned to be a local leader in addressing consumption-based emissions, helping to limit global warming and avoid the worst impacts of climate change.

Appendix A: Methodology

General Overview

The consumption-based emissions inventory (CBEI) is not a direct measurement of individual households' consumption or behavior. Instead, a model (a series of complex calculations) is used to estimate consumption of goods and services and associated emissions. This approach uses a combination of real-world consumption or emissions data where available along with predictions based upon demographic, regional, and national averages.

Preparing a complete CBEI involves multiple sub-models, but each sub-model follows the same general formula, described below.

1) Select a survey

First, a nationwide survey , conducted by the US federal government, that focuses on an important element of the inventory is selected. The US sub-models are built using the Consumer Expenditures Survey (CEX), the National Household Travel Survey (NHTS), and the Residential Energy Consumption Survey (RECS).

These surveys are used to build the full suite of models for the CBEI. CEX provides data used to model all sub-categories of consumption except for gasoline and home energy use. NHTS provides data for the vehicle miles traveled model, which translates into gasoline usage. RECS provides data for the home energy use models including electricity, natural gas, and other heating fuels.

2) Identify key household characteristics

Next, household characteristics are identified which are both included in the survey and for which nationwide data from the US census and other data sources are available. These data include variables like household size, income, vehicle ownership, etc. Geography, climate, and other relevant data are also included where applicable.

3) Build a predictive model

With the nationwide survey and selected household and geographic characteristics, a computer program is run to identify how strongly each of those household characteristics correlate with the survey results. This technique is called multiple linear regression, and is a type of machine learning. The computer sees many input data (the household and geographic characteristics) and learns how to predict what the outcome will be (the survey result). The computer then provides an equation that takes each of those household and geographic characteristics and produces an estimated result.

A single linear regression might take this form:

$$y = mx + b$$

where y is the survey result (dependent variable), x is the household and geographic characteristics (independent variable), m is the computer's predicted correlation between x and y (slope), and b is a fixed value that adjusts for any underlying base discrepancy between x and y when x is equal to 0 (intercept).

In multiple linear regression, the equation takes on a more complex form:

$$y = m_1x_1 + m_2x_2 + m_3x_3 + \ldots + b$$

where in this case, each x (x_1, x_2, x_3, etc.) is a different household or geographic characteristic, with its own unique correlation (m_1, m_2, m_3, etc.) that together add up to make the overall result. The number of x variables depends on the sub-model and available data. Almost all sub-models use at least six variables ($\ldots x_6$), with some using a dozen or more to get the most accurate prediction possible.

In addition, many of the values considered do not scale linearly. Instead, the models often look more like this:

$$\ln(y) = m_1x_1 + m_2{*}\ln(x_2) + m_3x_3 + \ldots + b$$

where the survey result might actually be scaled as a natural log (ln) variable, and some of the household and geographic characteristics are also calculated using its natural log (or sometimes both its ordinary and natural log values). This generally occurs in cases where there are nonlinear effects from household characteristics, and smaller values have different implications than larger values. For example, a household of two is typically two adults, whereas a household of three typically includes a child, which can significantly change consumption patterns. Similarly, consumption patterns based on income change significantly once basic needs are met and "luxury goods" start being consumed.

4) Run the model using local data

After these multivariate logistic regression models are built (see above), local data is then collected to be used in the model. These data consist mostly of census and climate data, from federal sources including the US Census Bureau, the National Oceanic and Atmospheric Administration (NOAA), but also include things like energy prices, inflation rates, fuel economy, and emission factors from sources including the Energy Information Agency (EIA), the Bureau of Labor Statistics (BLS), the Department of Energy (DOE), and the Environmental Protection Agency (EPA). Those values are transformed to fit the required inputs to the model, and then the model is run with that local data as the independent (x) variables in the model.

In some census tracts, local data is a poor fit for the models. Because the models are trained on a limited set of survey data, local outlier values can produce unreasonable results.

For instance, universities can result in unrealistic estimates of things like household size. These significant outliers are corrected to be more realistic estimates of local conditions for typical households in these instances. Extremely wealthy communities where the average household incomes well in excess of $300,000/yr) are also an outlier and are adjusted downwards. Much of the luxury spending at these higher income levels is very low-emission due to spending money on intangibles like brand value. For example, luxury clothing and cars have similar emissions as non-luxury goods, but cost significantly more due to the brand, and so adjusting highest-income households downwards preserves the accuracy of the emissions estimates.

5) Calculate emissions

After calculating consumption using the models, emissions are calculated. Most consumption emissions are calculated using the US EPA's US Environmentally Extended Input-Output Model (USEEIO), which bridges the gap between consumption (dollars) and emissions ($MTCO_2e$). This model includes data on emissions by sector and supply chain stage, allowing for differentiation between emissions associated with production, transport, wholesale, and retail, for all US emissions. Emissions associated with fixed capital investments (e.g. buildings & infrastructure construction, excluding residential construction) are also incorporated across all sectors.

Electricity emissions are calculated using EPA's Emissions and Generation Resource Integrated Database (eGrid) emission factors, detailed at the zip code level and then scaled to any geography. For all other direct consumption of fuels (natural gas / methane, gasoline, etc.), the latest Intergovernmental Panel on Climate Change (IPCC) estimates of global warming potential (GWP) and best available academic literature are used to estimate life-cycle emissions. (IPCC GWP values are commonly used across the majority of emissions reporting protocols, such as the Global Protocol for Community-Scale GHG Inventories and the Local Government Operations Protocol). This includes fugitive emissions (e.g. undesired leaks of greenhouse gases) and non-CO_2 GHG emissions, as well as any additional climate forcing effects from other emissions (such as particulate matter or contrails).

When working with local jurisdictions, these national or grid average emission factors are replaced with the best available local data. For Boulder, this includes electricity usage and emission factors, as well as water consumption.

6) Make final adjustments to consumption estimates

While the multiple linear regression model help to estimate consumption, the model does not perfectly resemble reality. These discrepancies are adjusted by comparing the model's predicted results with real-world data wherever available, and scaling the model outputs accordingly where real-world data isn't available.

To achieve this, the model results are compared with the actual results for the most granular level of data available. This can be national-level data (in the case of surveys), state-level data (in the case of transportation), or locality-level data (in the case of energy or water consumption). For cases where real-world data is available at the geographic scale of interest, the real-world data is used instead; otherwise, the model is run at the same geographic level at which data is available and use that to create a scaling factor, which is used to correct the locally modeled data. For example, modeled state-level energy use is compared with real state-level energy data, and then used to generate a scaling factor to adjust each census tract's modeled energy use. This scaling correction is usually on the order of 10%.

Model Input Variables

The consumption models use the following six variables: household size, average income, vehicle ownership, home ownership, share of household respondents with a bachelor's degree or higher (educational attainment), and number of rooms (home size).

The vehicle miles traveled model uses household size, average income, vehicle ownership, home ownership, and educational attainment, along with commute time to work, drive alone to work, number of homes per square mile, number of employed people per square mile, employed people per household, family status, children per household, youth per household, adults per household, and Census region.

The home energy models use household size, average income, home ownership, and home size as well as detached home status, heating and cooling degree days, statewide average price of electricity, statewide average price of natural gas, and census division.

Technical Details

The Consumer Expenditures Survey (CEX) is the only annual national survey of household consumption in the United States. Within the CEX, there are a total of 95 categories and subcategories of expenditures for everything US households consume, including detailed breakdowns of food, utilities, home construction, transportation, household goods and services.

The CEX is used as the initial basis for our consumption models across all categories of expenditures. Because the smaller sub-categories have more uncertainty and error associated with them, EcoDataLab's models are generally developed at either first- or second-tier category level across the CEX dataset. After running the models at the local level, local consumption estimates are normalized to national data by using a scaling factor based upon the ratio of national modeled results to real-world national survey results, across each category of consumption.

CEX categories are then mapped to Personal Consumption Expenditures (PCE) developed by the Bureau of Economic Analysis (BEA). Each PCE maps to one or more sectors of the US economy, and each sector has associated full supply chain emissions available through the US EPA's USEEIO model. BEA's PCE Bridge Tables for 2012 allow for assigning emissions to cradle-to-gate, transportation to market, and trade stages. Custom emission factors (grams CO_2e per dollar of expenditure) are then created based on the detailed mapping of sectors, PCE and CEX categories. This converts average US household expenditures to total US emissions, broken down by each CEX category and in total.

These custom emission factors are then increased to account for embodied emissions in fixed capital investments (buildings and infrastructure). Emissions from fixed capital are attributed to each sector based upon that sector's economic weight. This results in a new, final emission factor (grams CO_2e per dollar of CE expenditure) that accounts for all lifecycle emissions associated with that category of expenditure.

However, these lifecycle emission factors based upon USEEIO data are only available for the year 2012. To calculate emissions in other years, they are adjusted backwards and forwards in time as needed using an average decarbonization rate (assumed 1% based on academic literature). Prior to calculating emissions, all modeled and real-world household expenditures are also normalized to 2012 US dollars using the category-specific Consumer Price Index (CPI) for each category.

While the CBEI models started with the CEX, greater accuracy in calculating emissions can be achieved by using other household surveys for specific sub-categories: namely, by using the National Household Travel Survey (NHTS) to model household vehicle miles traveled (VMT), and by using the Residential Energy Consumption Survey (RECS) to model household energy usage. These models are the most robust models that could be constructed using recent and relevant data, and in many cases are a very strong fit. For instance, at the state level, EcoDataLab's electricity and natural gas models have a goodness of fit R^2 value of about 0.87 and

0.72, meaning they explain about 87% and 72% of the variation in household energy use, for their respective categories of energy. When comparing with specific city and county-level data, these modeled results are typically within ~10% of the real-world data, providing sufficient accuracy for historical back-casting and local tract-level estimates of variation.

In preparing consumption-based emissions inventories, CEX-based modeled estimates of expenditures on gasoline, electricity, natural gas, and other fuels are replaced with results from these other sub-models. With these models, direct and indirect (well-to-pump) emission factors are applied for both fossil fuels and electricity consumed directly by households.

Gasoline emissions are based on US national average vehicle fuel economy data from the Department of Transportation. Electricity emission factors are based on US EPA eGrid region emission factors at the zip code level, and scaled to other geographies based on population, unless local emission factors are available (as is the case with Boulder)

Because of the combination of local characteristics to inform regression modeling and scaling based on real-world national data to capture general trends, this methodology allows for consistently tracking changes in the quantity of household consumption over time, and to estimate the impact of consumption on emissions using best-available sources.

As reported in the Consumption-Based Greenhouse Gas Emissions Inventory of San Francisco from 1990 to 2015[18], this consumption-based approach accounts for essentially all GHG emissions in the US economy but allocated to households and government. Figure 7 in that report shows that the CBEI correlates very closely to the traditional inventory (within 10%). One limitation of this approach is that imports are assumed to be produced with the same carbon intensity as domestic production; future work will likely incorporate a multi-regional input output model (MRIO) (such as Eora or Exiobase3) to account for the carbon intensity of imports. MRIO models allow for more granular analysis of trade between geographic regions, including between US counties and with other countries.

Limitations

Unlike other CBEI approaches, this model approach allows for some ability to see the effect of policy and to track changes over time. The current approach offers this

[18] CoolClimate Network, https://escholarship.org/uc/item/4k19r6z7

improved tracking by including more policy-relevant variables, including home size, household size, home ownership, education, income, population density, and vehicle ownership.

However, local changes in policy, behavior, infrastructure, and technology which might affect consumption or emissions in ways beyond the model variables are not included in the current approach. If a local policy changed consumption patterns or the carbon intensity of products or services consumed, we would not be able to monitor this with the current methodology. Additional data could supplement the approach in future studies.

The current approach does not include an estimate of total error. Ideally, each estimate of consumption and emissions would include uncertainty bounds and analysis of error. Potential sources of error include reporting error in household survey day, sampling error, model error, categorization error, and other errors typically associated with input-output models (in this case, the USEEIO). Most of these errors are known and could be propagated through formulas in the study in future research.

The carbon intensity of imported goods is also assumed to be the same as domestically-produced goods. The current model is unable to track the countries of origin of emissions associated with local consumption. This assumption may affect individual products, such as computers, but is unlikely to have a large impact overall since the United States has a large, fairly carbon-intensive production system, with considerable electricity production from coal, similar to many exporting countries. Future studies could incorporate a multi-regional input output model to provide better data on the effect of international supply chains on consumption-based emissions.

Lastly, it is also assumed that price corresponds with “value added” economic activity. If residents of an area purchase higher priced goods, then the methodology will linearly scale emissions up with prices. This scaling is appropriate if higher prices are the result of additional economic activity, such as importing products from abroad, but is problematic when prices are artificially raised, such as for branding purposes. Conversely, cheaper products will result in lower emissions in the model. Generally, it is assumed that price differences average out over thousands of households.

Appendix B: Opportunities for Individual Action

Examples of Individual Actions to Reduce Gasoline Consumption

Many Boulder households have little choice but to drive for most trips. As a result, switching to an electric vehicle (EV) is likely the most effective option for many households, though it is not cheap.

Depending on location and use case, some households can purchase one or more electric bicycles (e-bikes) to substitute for an automobile. E-bikes are bicycles that include an electric motor to assist pedaling, and can typically reach speeds of 20-28 mph. Some models include large cargo carriers capable of carrying kids, groceries, or even furniture. Boulder is working to expand safe infrastructure for biking, to further facilitate non-automobile mode choices.

Examples of Individual Actions for Reducing Natural Gas Use

Typically, the most effective ways for households to reduce their natural gas usage is to replace gas furnaces and water heaters with heat pumps, clothes dryers with electric alternatives, and gas cookstoves with induction cooktops. Local programs, such as EnergySmart and Partners for a Clean Environment, can help residents take advantage of energy efficiency and renewable energy opportunities. Each program offers free, one-on-one energy advising, financial incentives and unique programing to meet the needs of each participant. Both programs are currently centering their work on climate justice to reach historically marginalized populations that face the most climate risk.

Even with financial support, these replacement appliances and associated home electrical upgrades can be expensive, so energy efficiency improvements in the interim can also help reduce natural gas usage.

Examples of Individual Actions for Reducing Food Emissions

Households that aim to reduce emissions from food have two primary strategies they can use. First, avoiding food waste and only buying as much food as the household needs is one of the easiest - and most cost-effective - ways to avoid food emissions. Second, replacing meat and dairy with plant-based substitutes can lead to further large emissions reductions. Buying organic and locally grown food does not typically have much impact on emissions, but can provide other social and economic benefits.

Examples of Individual Strategies for Reducing Air Travel

Households that aim to reduce their air travel emissions typically avoid flying, take long-distance buses, or take a train instead when available. While Boulder is not served directly by any trains, there is bus service to Denver Union Station where Amtrak's California Zephyr train serves the San Francisco Bay Area and Chicago, with stops including Glenwood Springs, Grand Junction, and Winter Park, CO; Salt Lake City, Provo, and Green River, UT; Lake Tahoe (Truckee), Sacramento, and Emeryville, CA; and Omaha and Lincoln, NE. Amtrak also runs a Winter Park Express, typically January through March, running directly between Denver and Winter Park on Fridays, Saturdays, and Sundays.

Examples of Individual Actions for Reducing Electricity Emissions

Some common strategies for households to reduce their electricity emissions include energy efficiency improvements and/or switching to 100% carbon-free or renewable electricity.

To improve energy efficiency, households can improve insulation and weatherization, replace old lightbulbs with LEDs and ensure new appliances are EnergySTAR-certified, and use a smart thermostat to ensure heating and air conditioning only run when needed.

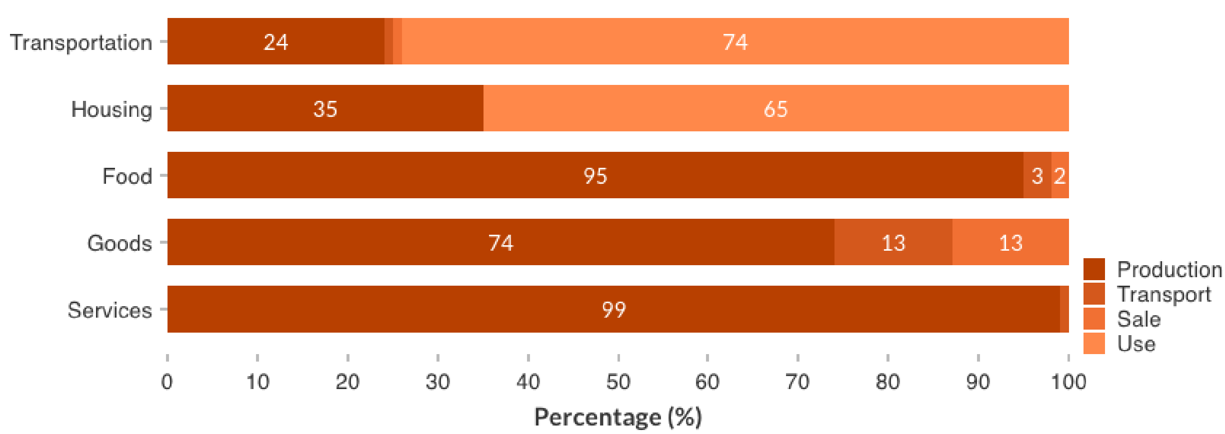
Both Boulder County and the State of Colorado offer incentives and rebates to support energy efficiency, weatherization, electrification, and EnergySTAR appliances.

Appendix C: Emissions Breakdown by Supply Chain Stage

Boulder’s consumption-based emissions inventory assumes all categories and sub-categories (except electricity) have the same emissions intensity as the US average. This means that the CBEI assumes every dollar spent, mile driven, or unit of energy used for home heating by Boulder residents has the same emissions as the average dollar, mile, or unit of energy spent in the US. (For electricity, a Boulder-specific emissions intensity was used).

The CBEI also assumes those emissions occur in the same places throughout the supply chain. Emissions are generated in production, during transport (by rail, sea, road, or air), in wholesale and retail, and use. In some cases, disposal also generates emissions; however, disposal also sometimes results in storing carbon that would otherwise be re-emitted, or avoiding emissions that would result from extraction and processing of raw materials. The chart below shows the share of emissions associated with production, transport, sale, and use for each overarching category of goods. Because disposal emissions are sometimes negative, such as from composting or recycling, they are not included on this chart.

Figure 19. Household emissions breakdown by supply chain stage - US average

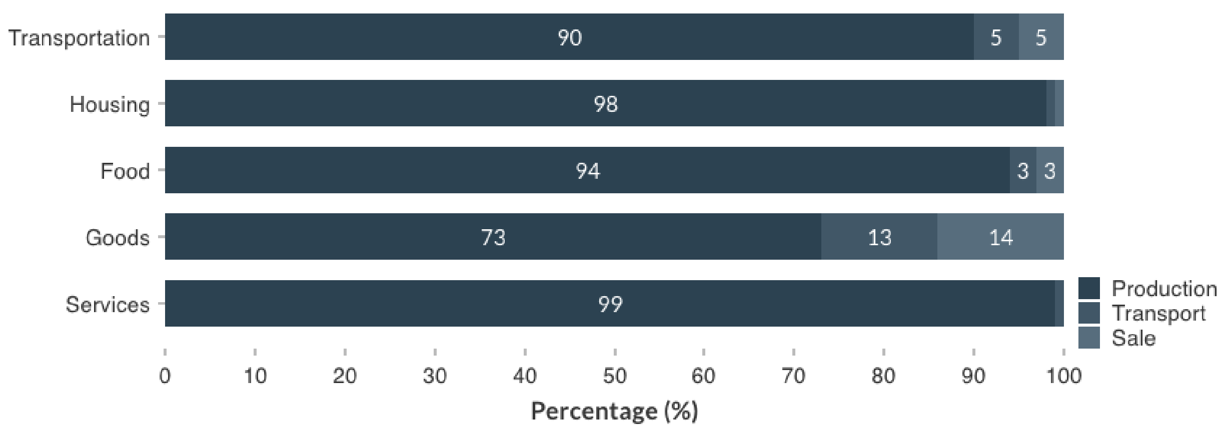


This chart shows, for each category of consumption, what percentage of emissions are associated with each life-cycle phase (production, transport, sale, and use).

Overall, household emissions from transportation and housing are dominated by "use phase" emissions - the burning of fossil fuels (such as gasoline or the methane in natural gas) for transportation or home heating energy. This "use phase," primarily gasoline combustion, makes up nearly 74% of household transportation emissions. For housing emissions, "use phase" emissions (electricity and home heating fuels) make up 65%.

For food, goods, and services, use phase emissions are practically zero. These categories have some transport and sale emissions, but are overwhelmingly dominated by production emissions. The chart below shows the pre-consumer (production, transport, and sale) breakdown of emissions by category.

Figure 20. Pre-Consumer Emissions Breakdown - US Average



This chart shows, for each category of consumption, what percentage of emissions are associated with each life-cycle phase prior to use (production, transport, and sale). These are the emissions associated with the production of goods and services prior to households acquiring them.

Pre-consumer emissions associated with transportation (that is, prior to a consumer using a vehicle) are predominantly from production (90%). Roughly 50% of these emissions are associated with the production of fuel (oil extraction & refining). The remaining 50% of emissions are from the production of vehicles and vehicle parts. Most of the transport emissions in this section derive from the transport of used vehicles, while sales emissions mostly derive from the sale of gasoline and other transportation fuels.

For housing, over 99% of pre-consumer emissions occur in production. This is dominated by the production of natural gas and the construction of homes, apartments, and other lodging (including hotels). The small portion of these emissions attributable to transport and sale are entirely due to the transport and sale of fossil fuels (and wood) used for home heating.

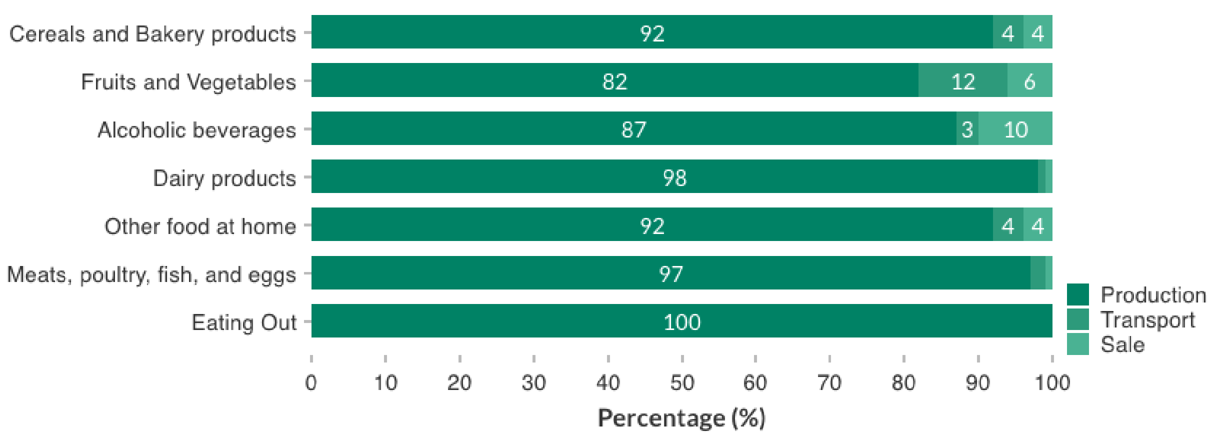
For food, roughly 95% of emissions occur in production. As discussed in the food breakdown below, food emissions primarily come from application of nitrogen fertilizers and enteric fermentation (methane released from digestion by cows and other livestock). These emissions significantly outweigh the emissions associated with transportation or sale of food.

For goods, only about 72% of emissions come from production. About 13% of emissions from goods comes from transportation, and 14% comes from retail. Transport emissions from goods disproportionately occur from truck travel, which make up over 90% of the total goods transport emissions (12% of goods total emissions). Similarly, over 90% of the emissions associated with the sale of goods comes from retail (13% of goods total emissions).

Like housing, pre-consumer emissions from services are overwhelmingly (99%+) from production. Services is primarily made up of activities like healthcare, education, entertainment, and various financial services; most of these involve little to no retail or transportation to provide these services.

Figure 21, below, shows what percentage of emissions are associated with production, transport, and sale for each sub-category of food.

Figure 21. Pre-Consumer Food Emissions Breakdown - US Average



For all food sub-categories, over 80% of emissions come from production. For fruits and vegetables, and alcoholic beverages, production emissions account for roughly 83% and 87% of pre-consumer emissions, respectively. Cereals and bakery products, as well as miscellaneous household food (spices, ingredients, etc.), have roughly 92% of their emissions from production. Meanwhile, meat and dairy products have over 97% of their emissions from production, while eating out has

99% of its emissions from production. Within all food sub-categories, transport emissions are overwhelmingly dominated by truck transport.

Meat and dairy products have significantly higher emissions (on both a per calorie or per dollar basis) than other foods. These extra emissions are virtually entirely in the production phase, which is why production is a higher-than-average share of emissions for meat and dairy.

Meanwhile, fruits and vegetables have predominantly production-phase emissions because the transport of food is relatively efficient, even over longer distances. As a result, fruits and vegetables from local farmer's markets are not necessarily lower emissions than those at large supermarkets. Because farmers typically bring relatively small quantities to the farmer's market, the transport may be much less efficient, which could result in a higher overall footprint than food that may have been grown further away but transported more efficiently.

Appendix D: Government Emissions

In the consumption-based emissions inventory, government agencies are considered final demand the same way households are, and so emissions associated with government operations and procurement are not attributed directly to households. However, these emissions are not insignificant – across the US, federal, state, and local governments had emissions totaling over 660 million metric $MTCO_2e$. Of this total, roughly 69% came from state & local governments, with the remaining 31% from the US federal government split between defense (24%) and non-defense sectors (7%).

If these government emissions were allocated to households across the US, it would be an average of 5.5 $MTCO_2e$ per household. For Boulder, this would be an additional 233,068 $MTCO_2e$ citywide. These are "hidden" emissions that are not otherwise captured in the consumption-based emissions inventory, but still contribute to overall emissions nationally and globally.

Like households, government emissions include transportation, buildings, and procurement of goods & services. At the federal level, transportation emissions include the use of military vehicles, aircraft, USPS trucks, and Amtrak trains. State and local governments also operate vehicles which include local public transit trains and buses, police and firefighting vehicles and aircraft, ambulances, roadway repair and maintenance, and more. Because public transit is heavily subsidized in the US and associated emissions are not directly related to consumer spending, these emissions are allocated to government instead.

Government emissions from buildings include natural gas used for heating and water heating, as well as electricity use associated with the operation of the building. Embodied emissions from construction are also included. Government buildings include agency or department offices, legislatures, public colleges and universities, local schools, ports and airports, courts and prisons, post offices, military bases, some museums, research laboratories, libraries, water treatment plants, some hospitals, and more.

Governments spend large sums investing in infrastructure and take on those associated emissions. Roads, highways, and bridges all have large emissions associated with their construction due to the large amounts of asphalt, concrete, and steel used. Governments also build and maintain local water supply and resources, as well as some railway and public transit infrastructure, with additional emissions associated. Lastly, other procurement of a wide variety of materials and services, ranging from office supplies to special firefighting foams, all have emissions associated with them.