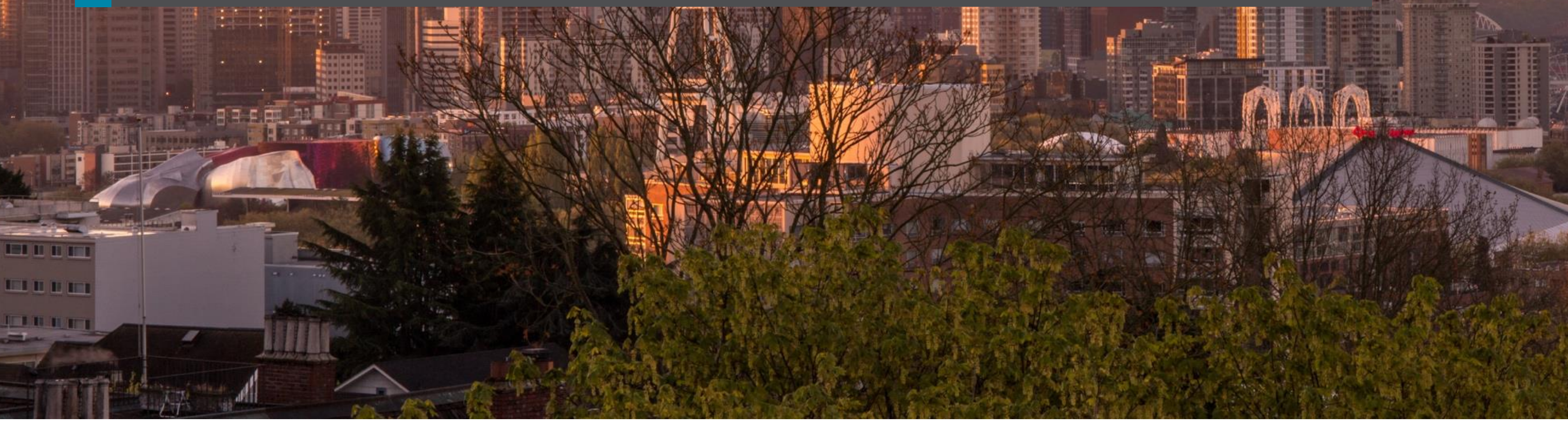
Seattle Communitywide Consumption-based GHG Emissions Inventory

Puget Sound Regional Emissions Analysis

EcoDataLab and Stockholm Environment Institute

FINAL REPORT

February 2023



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Dear Friends and Partners,

Climate change is having a profound effect on the world around us—impacting communities, ecosystems, and people's health. These changes are harmful for everyone, but our frontline communities bear a disproportionate burden of the harm. As a local government, the City of Seattle can and is taking meaningful steps towards lessening these harms.

As part of our efforts to address climate change, the City of Seattle, for the first time, has conducted a *Consumption-Based Emissions Inventory* for the city. This is an estimate of the greenhouse gas (GHG) emissions associated with the food Seattle residents eat, the things we buy, how we travel, and the homes we live in, no matter where those emissions are produced. Like a growing number of cities around the world that are evaluating their consumption-based emissions, Seattle recognizes that cities are centers of consumption and that cities have significant potential to influence global emissions.

When viewed alongside Seattle's geographic-based emissions inventory, which calculates all emissions that occur within the city's borders from transportation, buildings, and waste, this analysis gives us a better understanding of the full range of our community's impacts on global GHG emissions. **Seattle's consumption-based emissions are two to four times larger than our typical geographic-based emissions.** We are committed to measuring and managing the complete scope and scale of our climate pollution and identifying where the opportunities are for our greatest impact. At its core, this is an equity issue: Black, Indigenous, and People of Color (BIPOC) and low-income communities are more exposed to and harmed by climate pollution yet contribute significantly less to emissions.

Seattle has multiple paths available to reducing consumption-based emissions and is committed to mitigating climate impacts using a comprehensive equity-centered approach. The City has been an international leader in climate policy, environmental justice, solid waste management, water stewardship, and resource conservation for decades, thanks to public support for environmentally focused programs and thoughtful planning. Under the framework of Mayor Harrell's One Seattle Climate Justice Agenda, Seattle is investing in policies and programs aimed at building an equitable clean energy economy, ensuring a just transition away from fossil fuels, and building healthy and climate resilient communities. Seattle is also building toward an inclusive circular economy, where all materials, water, and resources are valued, and nothing is wasted.

We know the road ahead is long and this is just a first step. We are ready to come together as One Seattle to do the work to center community in our efforts to address consumption-based emissions and offer direct benefits to Seattle's local economy, community resilience, and public health.

Ultimately, the effort to address consumption-based emissions will require collaboration between residents, community organizations, businesses, and the public sector. We thank you for your support and look forward to opening a conversation on how we can together address consumption-based emissions.

Jessyn Farrell
Director
Seattle Office of Sustainability & Environment

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General Manager & CEO
Seattle Public Utilities

Glossary of Terms

Circular Economy: A circular economy aims to ensure that materials and products keep cycling through new uses and seeks to stop waste from being produced in the first place. The circular economy includes actions such as buying and using less, making and buying products that last longer, designing products and systems for reuse and remanufacture, repair, sharing, donating, or re-selling items so others can use them.

Consumption-Based Emissions Inventory: A consumption-based emissions inventory (or 'CBEI') is an estimate of the greenhouse gas (GHG) emissions generated by the activity of all residents of a geographic area. It accounts for the emissions associated with all the goods and services consumed within the community, no matter where they are produced.

Embodied Emissions: Refers to the emissions associated with the construction, manufacture, or production of a good rather than the emissions created when that specific good is in use i.e. the carbon footprint of the materials used by that good. Also referred to as 'embedded emissions' or 'embodied carbon emissions'.

Geographic-Based Inventory: A geographic-based inventory looks at all emissions that occur within the city's borders. These focus primarily on GHG emissions from energy use within the city boundary, through direct combustion (i.e. transportation) or the consumption of grid-supplied electricity, heating and/or cooling, as well as GHG emissions from the treatment of waste. Also referred to as a 'Sector-Based Inventory' or a 'Traditional Inventory'.

Global Warming Potential (GWP): Greenhouse gases (GHGs) warm the Earth by absorbing energy and slowing the rate at which the energy escapes to space; they act like a blanket insulating the Earth. Different GHGs can have different effects on the Earth's warming. Two key ways in which these gases differ from each other are their ability to absorb energy (their "radiative efficiency"), and how long they stay in the atmosphere (also known as their "lifetime"). The Global Warming Potential (GWP) was developed to allow comparisons of the global warming impacts of different gases. Specifically, it is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2)

Greenhouse Gas (GHG) Emissions: GHGs refer to a set of gases – carbon dioxide, methane, nitrous oxide, and fluorinated gases – that trap heat in the atmosphere. In the context of GHG inventories, GHG emissions refer to the release of these gases into the atmosphere primarily as a result of human activities.

Metric Tons of Carbon Dioxide Equivalent (MTCO2e): The unit of measurement of greenhouse gas emissions in this report. The unit 'CO2e' represents an amount of a GHG whose atmospheric impact has been standardized to that of one unit mass of carbon dioxide (CO2), based on the global warming potential (GWP) of the gas.

Executive Summary

A **consumption-based emissions inventory (or 'CBEI')** is an estimate of the greenhouse gas (GHG) emissions generated by the activity of all residents of a geographic area. Simply put, this inventory estimates the greenhouse gas (GHG) emissions associated with the food Seattle residents eat, the things we buy, how we travel, and the homes we live in, no matter where those emissions are produced. The more traditional or 'geographic-based' emissions approach used by most cities to date does not provide a complete picture of GHG emissions generated by the goods and services used in a city. This is because a geographic-based emissions inventory typically excludes the emissions that occur *outside* the city, such as the extraction of raw materials, manufacturing, and global transportation. A C40 analysis has found that in most cities (around 80% of C40 member cities), consumption-based GHG emissions are greater than geographic-based emissions.[1] Cities are centers of consumption and have significant potential to influence global emissions, and in recognition of this, a growing number of cities around the world are evaluating their consumption-based emissions.[2] When viewed alongside a geographic-based emissions inventory, cities can use a CBEI analysis to gain a better understanding of a broader range of global GHG impacts and reduction opportunities.

Seattle has partnered with King County and other regional agencies on the Puget Sound Regional Emissions Analysis, a component of which is this CBEI analysis for Seattle for the calendar year 2019. This CBEI provides Seattle with a baseline for measuring the impacts of our consumption on global GHG emissions, using the best available approach from the CoolClimate Network at UC Berkeley.[3] This analysis, prepared by EcoDataLab and Stockholm Environment Institute, will help provide insights on how to reduce our consumption-related climate impacts.

The CBEI analysis shows that in 2019, the typical Seattle household was responsible for roughly 33 metric tons of CO_2e annually (MTCO_2e), or about 16 MTCO_2e per person. For context, 33 MTCO_2e is equivalent to 7 gasoline-powered passenger vehicles driven for one year.[4] It is important to note that Seattle's total per household emissions are lower than King County's as a whole (42 MTCO_2e) and the US average (45 MTCO_2e). With 343,988 households in the city, this is a total of roughly **11 million MTCO_2e** in 2019 attributable to residents of Seattle.

These emissions are broken out into five areas: transportation, housing, food, goods, and services (the descriptions of the specific items covered in each area are provided in Table 2). **Figure 1** provides an overview of the city's average per-household emissions. Transportation was the single largest category of emissions, followed by food. Gasoline was the single largest source of emissions among all sub-categories.

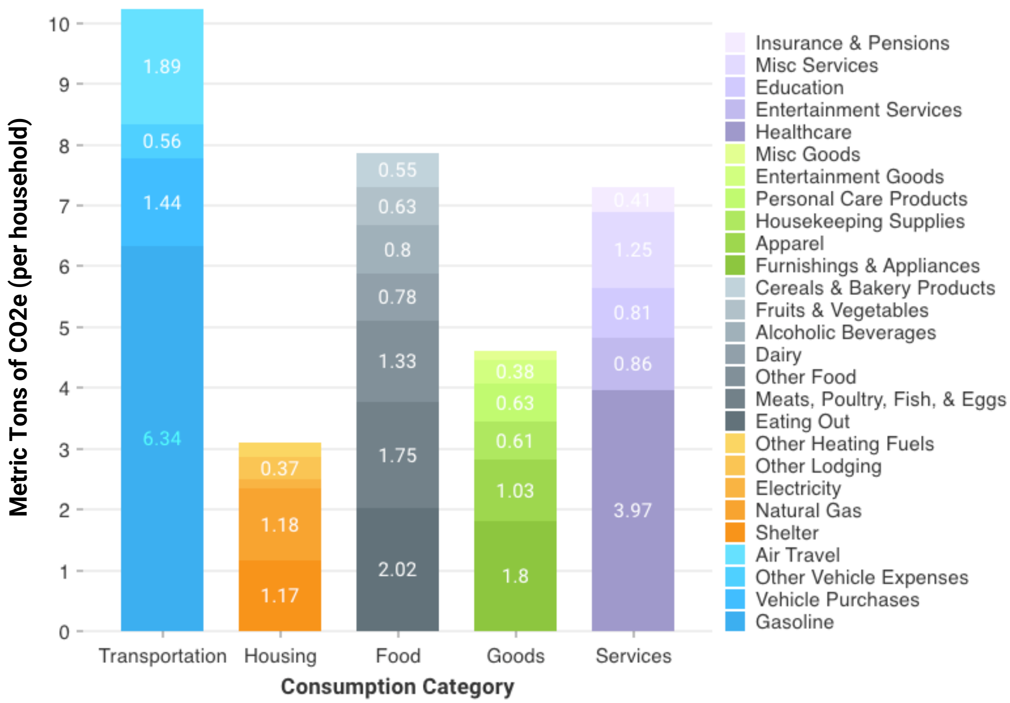
[1] https://www.c40knowledgehub.org/s/article/Consumption-based-GHG-emissions-of-C40-cities?language=en_US

[2] https://sustainableconsumption.usdn.org/initiatives-list/estimating-consumption-related-emissions

[3] https://coolclimate.berkeley.edu/

[4] https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Figure 1. Summary of Results of City of Seattle Consumption-based Emissions Inventory, 2019



The City of Seattle is committed to addressing consumption-based emissions, and this inventory is an important first step in understanding how to do so. Seattle has been an international leader in climate policy, solid waste management, water stewardship, and resource conservation for decades, thanks to public support for environmentally-focused programs and thoughtful planning. Under the framework of the One Seattle Climate Justice Agenda, Seattle is investing to support policies and programs aimed at building an equitable clean energy economy, ensuring a just transition away from fossil fuels, and building healthy and climate resilient communities. Seattle is also building toward an inclusive circular economy, where all materials, water, and resources are valued, and nothing is wasted.

The inventory highlights the continued importance of our efforts around transitioning away from fossil fuels in our transportation and buildings, and shines a light on the opportunity to reduce greenhouse gas emissions from the food we eat, the things we buy, and the materials that go into building our homes. This inventory will help inform and prioritize our existing climate programming and policies and will initiate further exploration on ways that the city should be addressing consumption-based emissions.

Seattle has multiple paths available to reducing consumption-based emissions, and is committed to mitigating climate impacts using a comprehensive approach. Actions that reduce consumption-based emissions will also offer direct benefits to Seattle's local economy, community resilience, and public health. Ultimately, the effort to address consumption-based emissions will also require collaboration between residents, community based organizations, businesses, and the public sector.

Introduction

A **consumption-based emissions inventory (or 'CBEI')** is an estimate of the greenhouse gas (GHG) emissions associated with the activity of all residents of a geographic area. It accounts for the emissions associated with all the goods and services consumed within the community, no matter where they are produced. Seattle's consumption-based emissions may occur anywhere in the world, as long as they are directly or indirectly the result of activities of Seattle residents. This includes 'embodied' emissions associated with the production, transportation, use, and disposal of goods, food, and services consumed in Seattle. It is equivalent to a personal household carbon footprint estimate, except calculated for all households in a jurisdiction.

Cities are a focal point for consumption and have significant potential to influence global emissions, and in recognition of this, a growing number of cities around the world are evaluating their consumption-based emissions.[5] The more traditional or 'geographic-based' emissions approach used by most cities to date does not provide a complete picture of GHG emissions generated by the consumption of goods and services within a city. This is because a geographic-based emissions inventory excludes the emissions that occur *outside* the city, such as the extraction of raw materials, manufacturing, and global transportation.

> *"While cities may not have much direct influence over the carbon intensity of power used in the manufacturing process of an imported product, or whether that product is transported by train or truck, as end users and centres of innovation and change, they do offer many opportunities to transform urban lifestyles into more sustainable ones to help reduce consumption-based GHG emissions. This can be achieved through a combination of resource productivity strategies and consumer policies, targeting carbon intensive consumption categories and lifecycle phases with the highest emissions, and supporting shifts in consumption to goods and services with lower emissions, including through public procurement."*
>
> ***Consumption Based Emissions of C40 Cities, C40 Cities***

When viewed alongside a geographic-based emissions inventory, cities can use a CBEI analysis to gain a better understanding of the full range of impacts and GHG reduction opportunities for residents within a community. Local communities can benefit from knowing the full impact of their consumption to better understand how they can help reduce emissions. This is especially important in cities such as Seattle: Seattle is a net exporter of emissions – the emissions of the goods and services it consumes predominantly occur outside of the city (as opposed to cities which do have significant local emissions from production or manufacturing activities that serve residents of other locations). A C40 analysis has found that in most cities (around 80% of C40 member cities), consumption-based GHG emissions are greater than geographic-based emissions.[6]

Seattle has partnered with King County and other regional agencies on the Puget Sound Regional Emissions Analysis, a component of which is this CBEI analysis for Seattle for the calendar year 2019. This CBEI provides Seattle with a baseline for measuring the impacts of our consumption on global GHG emissions, using the best available approach from the CoolClimate Network at UC Berkeley.[7] This analysis, prepared by EcoDataLab and Stockholm Environment Institute, will help provide insights on how to reduce our consumption-related climate impacts.

[5] https://sustainableconsumption.usdn.org/initiatives-list/estimating-consumption-related-emissions
[6] https://www.c40knowledgehub.org/s/article/Consumption-based-GHG-emissions-of-C40-cities?language=en_US
[7] https://coolclimate.berkeley.edu/

Consumption-Based Emissions Methodology

What are the differences between a Consumption-Based Emissions Inventory and a Geographic-Based Emissions Inventory?

In a **geographic-based inventory,** a city looks at **all emissions that occur within the city's borders**. These focus *primarily* on GHG emissions from energy use within the city boundary, through direct combustion (e.g. transportation) or the consumption of grid-supplied electricity, heating and/or cooling, as well as GHG emissions from the treatment of waste. A geographic-based inventory will consider the emissions from local businesses and visitors, but typically do not include anything outside the city's boundaries.

In contrast, **consumption-based emissions inventories** 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.** For example, this CBEI considers the full emissions associated with the production of food for residents of Seattle – including emissions from fertilizer (or feed, in the case of meat), transport, wholesale, and retail. Meanwhile, a geographic-based inventory would only consider the emissions that occur within city limits, including last-mile delivery and retail.

> **Explainer: Owning and driving a car in Seattle**
>
> A geographic-based inventory and a consumption-based inventory would both capture the emissions generated by your car while being driven in Seattle. A consumption-based inventory would *also* include emissions generated in sourcing the raw materials for your car and assembling your car in a factory. Some of these emissions likely occurred outside the U.S. and some inside this country, but outside of Seattle.

Consumption-based emissions inventories do not include emissions from visitors or from businesses that sell goods and services outside of the area of study. Instead, CBEIs account for emissions associated with residents' travel to other cities, as well as the emissions associated with producing the goods and services they purchase or consume. These emissions may occur anywhere in the world. Local emissions from the production of goods and services are counted in CBEIs only to the extent that they are also consumed locally. For example, clothing produced in Seattle but sold to people residing outside of the City would be excluded; clothing purchased by Seattle residents – regardless of where it is produced – would be included. As a result, the CBEI does not evaluate locally occurring emissions associated with consumption from people residing outside of the City, such as visitors, tourists, or other businesses. Consumption-based emissions from government operations are also excluded in the CBEI, as a CBEI focuses on residential consumption.

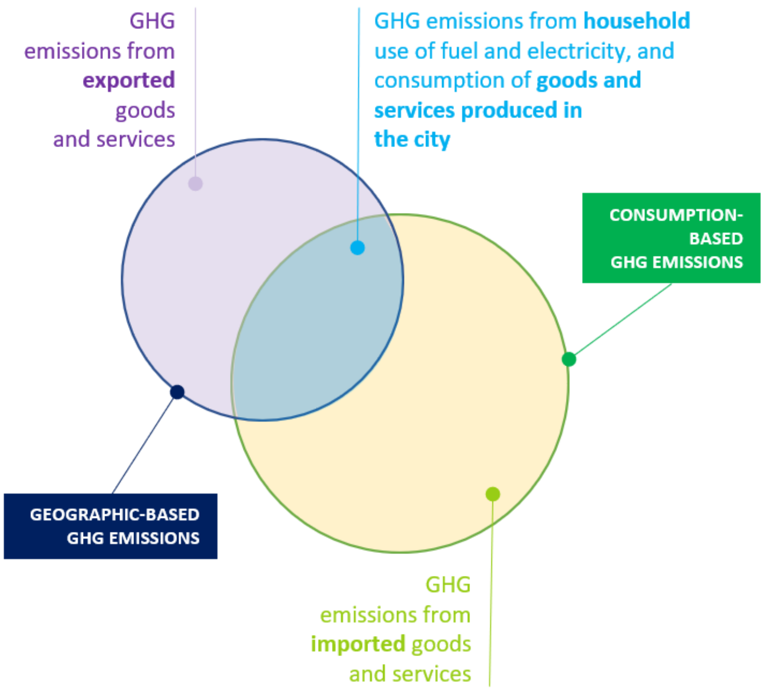
It is important to note that:

(1) **Geographic and consumption-based approaches are complementary analyses, and are useful for different purposes.** A CBEI is most useful for understanding where embodied emissions generated outside city boundaries constitute a significant portion of the carbon footprint of household consumption, and help communities understand how the consumption of specific goods and services drives GHG emissions on a global scale. A geographic-based emissions inventory tracks emissions and informs policies related to energy use in buildings and transportation, along with emissions from in-city industrial and waste sources.

(2) **There may be instances in which consumption-based emissions may overlap with geographic-based emissions**. For example, both will look at residents' local, direct emissions such as emissions produced when residents burn gasoline for local car trips. In addition, the City of

Seattle's geographic-based inventory and consumption-based inventory both include estimates for emissions from air travel that Seattle residents are responsible for.

Figure 2. Consumption-Based Emissions Inventory and Geographic Based Emissions Inventory (adapted from C40)



How are consumption-based emissions calculated?

Because consumption-based emissions occur anywhere in the world, it is virtually impossible to calculate them directly from activity data (as occurs in a geographic-based inventory). Instead, household consumption and emissions are estimated using a model. Consumption-based emissions are modeled based on local variables such as income and vehicle ownership, and on scientific studies that tie these variables to consumption-based emissions. This model takes into consideration six key household variables: household size, household income, vehicle ownership, home size, educational attainment, and home ownership. These variables often have clear, direct effects on consumption. For instance, larger homes generally take more energy to heat or cool, more people per household also means more food consumed per household, and households with a college degree generally spend more money on education services.

Table 1 compares the values of these household characteristics in Seattle with those of the US average:

Table 1. Household characteristics, Seattle vs United States. (Source: American Community Survey, US Census)

Household Characteristic	Seattle	US
Average Income	$131,715	$88,783

Household Characteristic	Seattle	US
Vehicle Ownership	1.34	1.82
Household Size (number of people)	2.11	2.61
Home Size (total number of rooms)[8]	5.05	6.57
Home Ownership	44%	64%
Educational Attainment (college degree)	69%	35%

The 2019 emissions profile for Seattle is based on a "typical" household, using the average household characteristics for Seattle as shown above. Most actual households in the city differ in one or more ways; and households with different characteristics are expected to have different emissions profiles.

See Appendix B for the detailed methodology.

[8] As defined by the U.S. census, a room is one that is 'separated by built-in archways or walls that extend out at least 6 inches and go from floor to ceiling'. Includes bedrooms, kitchens etc. and excludes bathrooms, porches, balconies, foyers, halls, or unfinished basements. https://www.census.gov/acs/www/about/why-we-ask-each-question/rooms/

Seattle Consumption-Based Emissions Inventory Summary of Results

In 2019, the typical Seattle household was responsible for roughly **33 metric tons of CO_2e** annually ($MTCO_2e$), or about 16 $MTCO_2e$ per person. For context, 33 $MTCO_2e$ is equivalent to 7 gasoline-powered passenger vehicles driven for one year.[9] With 343,988 households in the city, this is a total of roughly **11 million $MTCO_2e$** in 2019 attributable to residents of Seattle.

These emissions are broken out into five areas: transportation, housing, food, goods, and services (the descriptions of the specific items covered in each area are provided in Table 2). Transportation was the single largest category of emissions, followed by food. Gasoline was the single largest source of emissions overall, among all sub-categories. **Figure 3** provides an overview of the city's average per-household emissions. The actual emissions of any particular household could vary significantly from this average based on household size, spending, housing type, travel, and other discretionary and non-discretionary types of consumption.

Figure 3. Summary of Results of City of Seattle Consumption-based Emissions Inventory, 2019

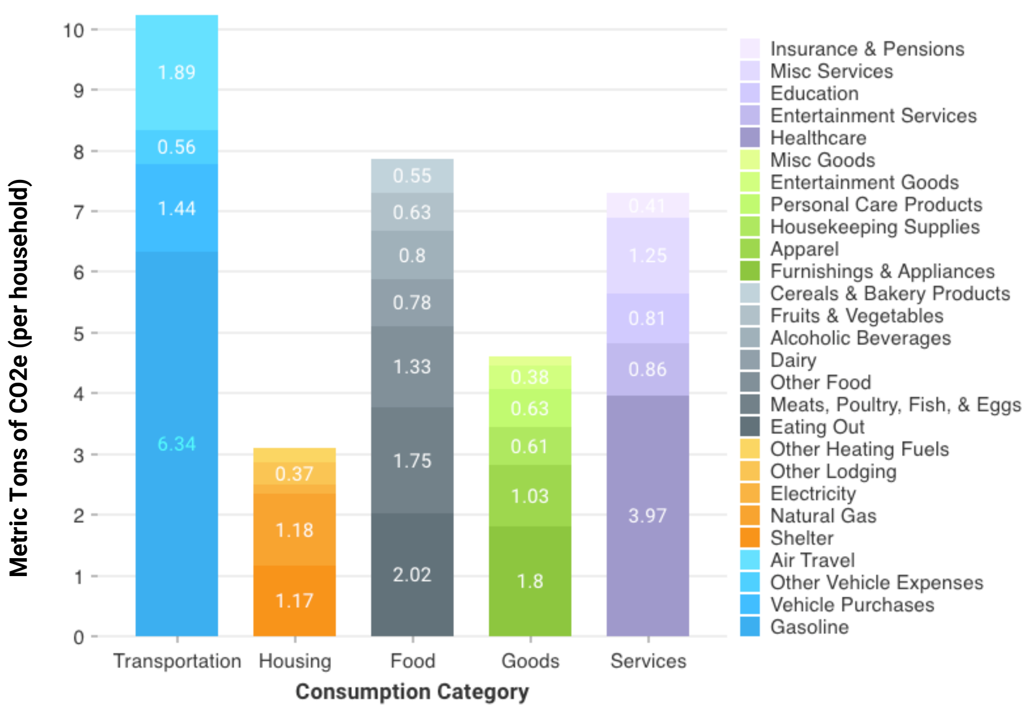


Table 2. Consumption Category Descriptions

Transportation	Gasoline	Gasoline used in personal vehicles
	Vehicle Purchases	Cars and other vehicles purchased by Seattle residents
	Other Vehicle Expenses	Maintenance, financing, insurance, rentals
	Air Travel	Fuel used in air travel conducted by residents of Seattle

[9] https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Housing	Shelter	Owned and rented dwellings
	Natural Gas	Natural gas used in Seattle households
	Electricity	Electricity used in Seattle households
	Other Lodging	Hotels, motels, nursing homes, etc.
	Other Heating Fuels	Propane and other fuels
Food	Eating Out	Emissions associated with the food production, energy emissions, building construction, and furnishings for restaurants, fast food, food trucks, and other food away from home consumed by Seattle residents
	Meats, Poultry, Fish & Eggs	Lifecycle emissions associated with meat, poultry, fish, and eggs purchased by Seattle residents
	Other Food	Nonalcoholic beverages, sweets, seasonings, miscellaneous foods
	Dairy	Milk, cream, cheese, and other dairy products consumed by Seattle residents
	Alcoholic Beverages	Beer, wine, liquor consumed by Seattle residents
	Cereals & Bakery Products	Cereals, bread, pastries, etc. consumed by Seattle residents
	Fruits & Vegetables	Fresh & processed fruits & vegetables
Goods	Apparel	Clothing & footwear
	Housekeeping Supplies	Laundry, cleaning supplies, postage, misc household products
	Personal Care Products	Grooming and makeup supplies, other misc personal care products
	Entertainment Goods	Audio and visual equipment and subscriptions, pets, toys, hobbies, etc.
	Misc Goods	Reading and tobacco supplies
Services	Healthcare	Emissions associated with hospitals & medical offices
	Entertainment Services	Fees & admissions to museums, zoos, concerts, etc.
	Education	Student loans, private tutoring, private school
	Misc Services	Personal care services, household operations, cash contributions, other misc services
	Insurance & Pensions	Life and other personal insurance, pensions & social security

Results In Context: Complementary Inventories

The City of Seattle has a long history of working to reduce GHG emissions generated by both city operations and residential and business activities, and tracking GHG emissions is an integral part of this work. As noted in the methodology section, the results of Seattle's Consumption Based Emissions Inventory must be seen as complementary to other existing inventories conducted by the City of Seattle:

- **Seattle's Geographic-Based Emissions Inventory:** Seattle's Office of Sustainability and Environment (OSE) tracks GHG emissions across the Seattle's buildings, transportation, and waste sectors through a geographic-based emissions inventory.[10]
- **City of Seattle Municipal Purchasing & Contracting Inventories:** Some City of Seattle departments have also conducted inventories of the emissions associated with their purchasing and contracting (their government spending) – including Seattle Public Utilities, Seattle City Light, and Seattle Parks & Recreation. These emissions are not captured by either the community-wide emissions inventory or the CBEI, since they are out of scope for a geographic-based inventory and not associated with household consumption.
- **City of Seattle Municipal Operations Inventories:** Specific City of Seattle departments have conducted inventories of the emissions associated with their government operations, and OSE tracks the energy use and emissions associated with most buildings owned by the city. For example, Seattle Public Utilities calculates the emissions associated with the electricity and fossil gas used in their buildings and facilities, the fuel used in their fleet, and other direct emissions related to their operations in an effort to be carbon neutral by 2030. These emissions are not captured by the CBEI since they are not associated with household consumption but they

[10] https://www.seattle.gov/environment/climate-change/climate-planning/performance-monitoring

are included in the city's geographic-based emissions inventory, although not as a separate category.

Ultimately, all of these emissions inventories provide information that the City of Seattle can use to inform its planning, programs, and policies to address the emissions produced by residents, businesses, municipal operations, and the wider community and to track progress toward our carbon-reduction goals. Table 3 summarizes these inventories and compares the scale and function of each of them.

Table 3. Comparison of magnitude and function of Seattle's Emissions Inventories

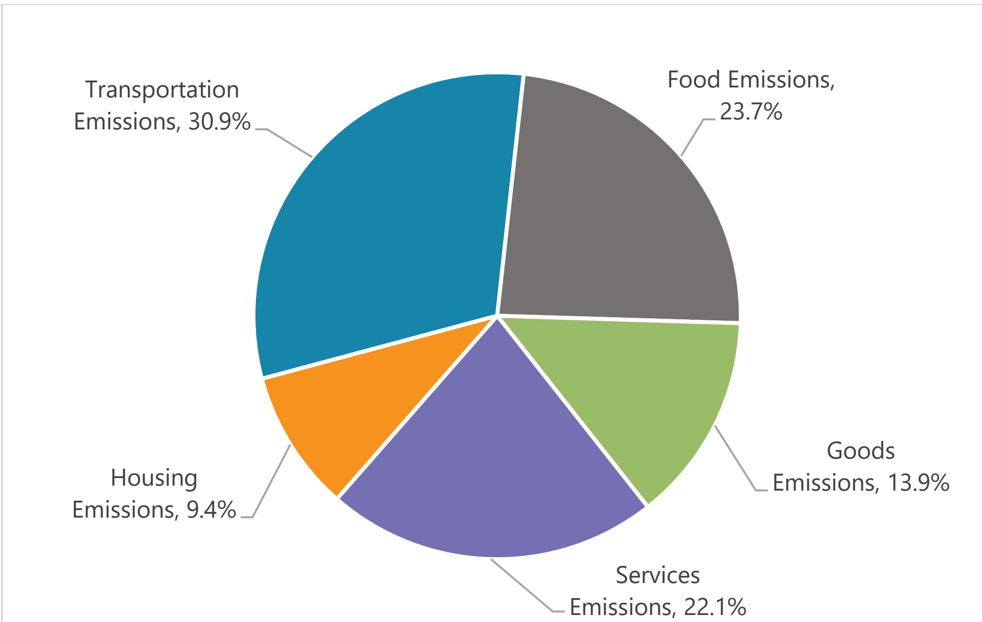
Inventory	Magnitude	Function
Seattle Consumption Based Emissions Inventory (2019)	★★★★★ (11 million MTCO2e)	Informs policies associated with the impact that consumption within the city has on global emissions.
Seattle Geographic-Based Emissions Inventory (2020)	★★☆☆☆ (3 million MTCO2e)	Tracks emissions in specific sectors (e.g., transportation, buildings, waste, etc.) and helps measure progress towards Seattle's climate reduction targets on a bi-annual basis. Also useful as a tool for high level climate policy and program development.
City of Seattle Department Purchasing & Contracting Emissions Inventory (e.g. Seattle Public Utilities) (2020)	★☆☆☆☆ (40 thousand MTCO2e)	Informs departmental decisions on purchasing and procurement practices to shift towards purchases with lower carbon intensity.
City of Seattle Department Operational Emissions Inventory (e.g. Seattle Public Utilities) (2020)	★☆☆☆☆ (17 thousand MTCO2e)	Informs departmental decisions on energy usage, energy efficiency, fleet and facility electrification etc.

Analysis of Results

Major Categories

Transportation, food, and services account for 31%, 24%, and 22% of emissions, respectively. Together, they account for over 76% of total emissions. Gasoline, healthcare, and eating out are the top three sub-categories, accounting for 19%, 12%, and 6% of total emissions, respectively – a combined 37%.

Figure 4. Overview of CBEI Results



Transportation

As shown in Figure 4, Transportation is the largest category of Seattle's consumption-based emissions (31%). The transportation category gasoline usage from individually owned vehicles, individually owned vehicle purchases & maintenance, and air travel. For an average household in Seattle, transportation accounts for 10.2 $MTCO_2e$ per year, per household.

Much of this comes from gasoline, which accounts for 6.3 $MTCO_2e$ per household, or 62% of the total transportation emissions. Gasoline consumption is the #1 source of consumption emissions in Seattle. There are two key components that drive gasoline consumption: vehicle ownership and the number of miles driven.

Nationwide, the average is 1.82 vehicles per household. A typical vehicle is driven over 11,000 miles per year, and so the average American household drives roughly 20,514 miles per year.
Meanwhile, Seattle households have an average of 1.34 vehicles per household and each vehicle is driven 10,349 miles per year, therefore the average Seattle household drives an estimated 13,867 miles per year.

Lower vehicle ownership strongly corresponds to lower household vehicle miles traveled (VMT). Vehicle ownership is also substantially determined by place of residence. Seattle households are much less car dependent than the average US household: only 45% drove alone to work, with an average commute time of 26 minutes.

For many individual households, air travel is a significant portion of emissions. However, for Seattle overall, air travel is only a small part of the city's consumption-based emissions, coming in at 1.9 $MTCO_2e$ per household on average (5.7% of total emissions). This varies significantly between households, however, largely due to income. In Seattle, as in the rest of the US, air travel is a luxury, 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. More recent data from Statista.com suggests that in 2019, 41% of the US population had never traveled by air, and another 28% flew only about once per year.

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; in comparison, the average fuel economy for new vehicles nationwide was 25.4 miles per gallon in 2020. However, due to additional warming effects from high-altitude particulate matter, as well as lifecycle production emissions of aviation fuels, air travel's overall emissions are roughly double what would be expected on a per gallon basis alone – making it more like driving a 35-50 mpg car. As a result, air travel may be more fuel-efficient than driving alone in an average vehicle, but usually not for two individuals driving together.

Air travel also often results in significant emissions due to the long distances traveled. A two-person, one-vehicle household may only drive 10,000 miles per year, but could easily fly 24,000 person-miles with just two cross-country trips per year (for example, one 3,000 miles per way trip equals 6,000 miles round trip per person or 12,000 miles for two people).

Food

As shown in Figure 4, Food is the second largest category of Seattle's consumption-based emissions (24%), accounting for 7.9 $MTCO_2e$ per household. The Food category includes all food consumed by residents of Seattle, broken down by meat, dairy, fruits & vegetables, and other foods consumed at home, as well as eating out. The single largest sub-category is eating out at 2 $MTCO_2e$ per household.

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 was responsible for about 10% of national emissions, or roughly 623 million metric tons of greenhouse gas emissions in 2019 (according to the US EPA). 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 the US' agriculture 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 animal digestion is nearly 30% of the US GHG emissions from agriculture. The decomposition of animal manure (also into methane) contributes another 12% of agriculture emissions. Nitrous oxide and methane combined account for 97% of emissions directly associated with agriculture.

The consumption-based inventory includes these direct nitrous oxide and methane emissions from agriculture, emissions from fixed capital investments in agricultural equipment and facilities (e.g., tractors, harvesters, combines, silos, stockyards, animal feeding operations, etc.), as well as emissions associated with transport and sale of food. Of these food-related emissions, direct emissions from agriculture are the vast majority of the emissions associated with food – generally around 67-80% of food emissions come directly from food production. For most foods, transportation comprises about 5% of the emissions, while wholesale and retail (e.g., grocery stores & suppliers) make up another 5-15%. Fixed capital investments (e.g., buildings and equipment) is estimated at typically around 13% of total emissions.

While nitrogen fertilizer is the single largest source of emissions associated with food nationally, meat & dairy are often the largest sources of at-home food emissions for households. In Seattle, meat, poultry, fish, eggs, and dairy combined account for 2.5 $MTCO_2e$ of emissions, while fruits & vegetables, cereals, and other foods account for another 2.5 $MTCO_2e$.

Despite being only a small fraction of overall calories, meat and dairy have an outsized impact on the typical household's emissions associated with food. This is because the emissions associated with meat and dairy 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 – 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. 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. 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. Food is the single largest material in Seattle's waste stream, even though food is banned from the garbage. Approximately 20% of residential garbage and 25% of business garbage is composed of food waste.[11]

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. This includes all purchased food, whether consumed or otherwise.

Eating out also contributes to a portion of food emissions. For the typical Seattle household, eating out is associated with roughly 2 $MTCO_2e$ 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,

[11] City of Seattle. Seattle Public Utilities. 2016 Commercial Waste Stream Composition Study. Final Report. https://www.seattle.gov/documents/Departments/SPU/Documents/2016CommercialWasteStreamCompositionStudy.pdf City of Seattle. Seattle Public Utilities. 2020 Residential Garbage and Recycling Stream Composition Study. https://www.seattle.gov/documents/Departments/SPU/Documents/Reports/SolidWaste/2020ResidentialWasteCompositionStudies.pdf

transportation, and construction of the building. In comparison, household emissions from cooking, transportation, and construction are allocated to the transportation and housing sectors. Because of the modeling approach used for the CBEI, which is based on household expenditure data, eating out estimates are a combination of all food consumed away from home, and specific categories of food purchased (such as meat, dairy, or fruits & vegetables) are not distinguished.

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.

Services

Services are the third largest category of consumption-based emissions for Seattle (22%). This category includes the emissions associated with things like healthcare, education, insurance & finance, and entertainment experiences like concerts and museums. Services account for 7.3 MTCO2e per household, and the single largest sub-category is healthcare at 4 $MTCO_2e$ per household.

Nationally, healthcare makes up roughly 18% of the US economy; in Seattle, healthcare emissions are about 13% of the typical household's carbon footprint. Healthcare emissions include emissions from hospitals and other medical facilities, pharmaceutical manufacturing, 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.).

Goods

Goods account for 14% of Seattle's consumption-based emissions, or 4.6 $MTCO_2e$ per household per year. This category includes all physical items purchased by the household (excluding items in other categories, such as food and gas). Goods includes things like furniture, apparel, personal electronics, clothing, toys, and books.

The largest sources of emissions from goods in Seattle comes from household furnishings and equipment (including miscellaneous household equipment, furniture, and appliances), accounting for 1.8 $MTCO_2e$ per household, as well as apparel (clothing), at 1.0 $MTCO_2e$ per household.

Housing

The Housing category is the smallest category of consumption-based emissions for Seattle (9%). This category includes household energy use, home construction and maintenance ("shelter"), and water usage. Overall, a typical Seattle household has 3.1 $MTCO_2e$ resulting from housing, with the largest single sub-category being shelter. Shelter produces 1.2 $MTCO_2e$.

Seattle's electricity emissions derive from Seattle City Light data showing an average electricity usage of 6,946 kWh per household in the city and a SCL-specific emissions factor of 20 grams per kWh[12]. The

[12] The Climate Registry, 2019 Emissions Factor

majority of the electricity SCL provides comes from carbon-free hydroelectricity. SCL offsets all of its operations and was the first carbon-neutral utility in the nation.[13] Roughly 58% of households in Seattle use electricity for heating.[14]

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

Burning fossil gas in homes not only contributes to CO_2emissions, but also to local (indoor and outdoor) air pollution. Fossil gas combustion produces carbon monoxide, nitrogen dioxide, fine particulate matter ($PM_{2.5}$), and formaldehyde, among other pollutants. When burned in furnaces for heating or water heating, these fumes are vented into the surrounding neighborhood, where they generally disperse at low concentrations. However, 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. 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.

The systems for the extraction, transport, storage, and distribution of methane nationwide (the primary ingredient of fossil gas) all 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_2 when considered over a 20-year time frame. As a result, even a small leakage rate of just 5% would mean that the leaked methane is a bigger contributor to climate change than the CO_2 from burning the other 95%. In 2019, the national average leakage rate throughout the entire fossil gas supply chain was about 2.3%.

Nationally, the EPA estimates about half of all methane leaks occur in production, with another 25% occurring in transmission and storage. Distribution and post-meter leakage each contribute about 10% to the overall leakage rate. The consumption-based inventory uses the 2.3% overall leakage rate.[15]Seattle's geographic-based inventory relies on data in Puget Sound Energy's own GHG emissions reports[16] to calculate the share of leakage in gas infrastructure attributable to consumption in Seattle.

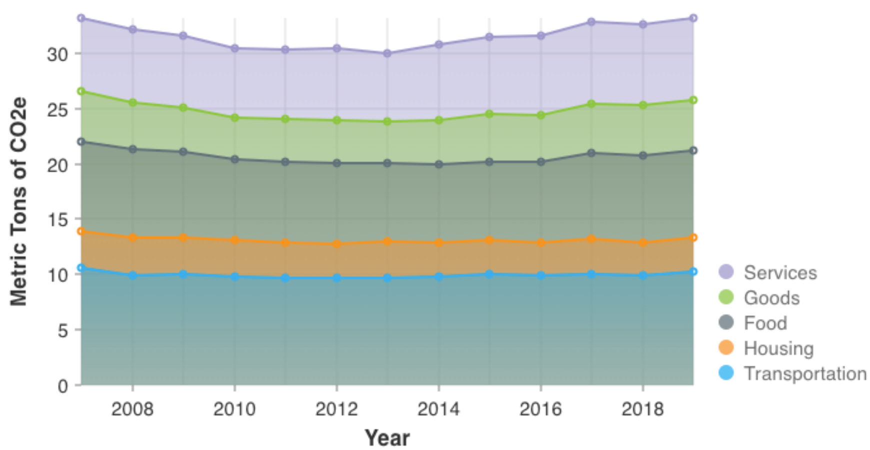
Fossil gas usage for Seattle is estimated at 224 therms per household, resulting in 1.2 $MTCO_2e$. Roughly 36% of households in the city use gas for heating.[17]

[13] https://www.seattle.gov/city-light/energy-and-environment
[14] https://censusreporter.org/tables/B25040/
[15] Assessment of methane emissions from the U.S. oil and gas supply chain, Science Journal (2018) https://www.science.org/doi/10.1126/science.aar7204
[16] https://www.pse.com/en/pages/greenhouse-gas-policy
[17] https://censusreporter.org/tables/B25040/

Historical Trends in Consumption-Based Emissions

Since 2007, Seattle's consumption-based emissions have held constant, only decreasing by 0.1%, or about 0.03 $MTCO_2e$ per household, as shown in Figure 5 below.

Figure 5. Historical CBEI trends for Seattle, 2007-2019 (per household)



Services and Goods have seen the largest increases, of 10% and 3%, respectively.

At the national level, household consumption-based emissions have declined by more than 12%. The electricity grid has been getting cleaner, vehicle fuel economy has been improving, and industries have generally been figuring out how to decrease emissions. However, Seattle has also seen significant demographic changes over this same time period. Population has grown at an unprecedented rate; from 2010 to 2020, Seattle's population grew by 21%.[18]

Since 2007, household incomes have increased by over $50,000, or 62%. Even after adjusting for inflation, this is still an increase of 33%. The share of households with a college degree has also grown substantially, from 54% to 69%. In addition, while electricity emissions have been falling in the rest of the country, Seattle has had virtually no emissions from electricity for over a decade due to its carbon neutral electricity grid.

Vehicle ownership and home ownership rates have declined slightly over this time period, but not enough to make a significant difference.

The charts below highlight the trends in these characteristics over time.

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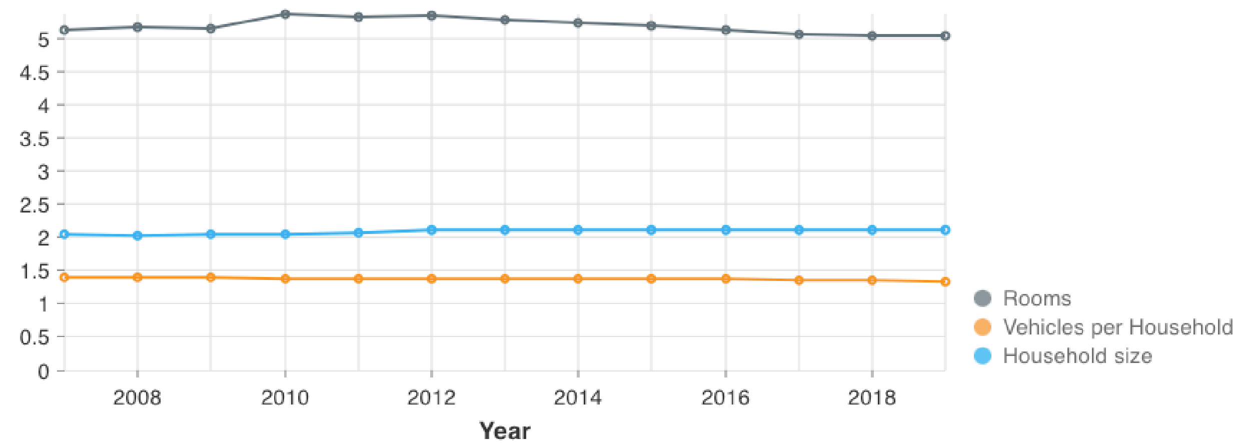
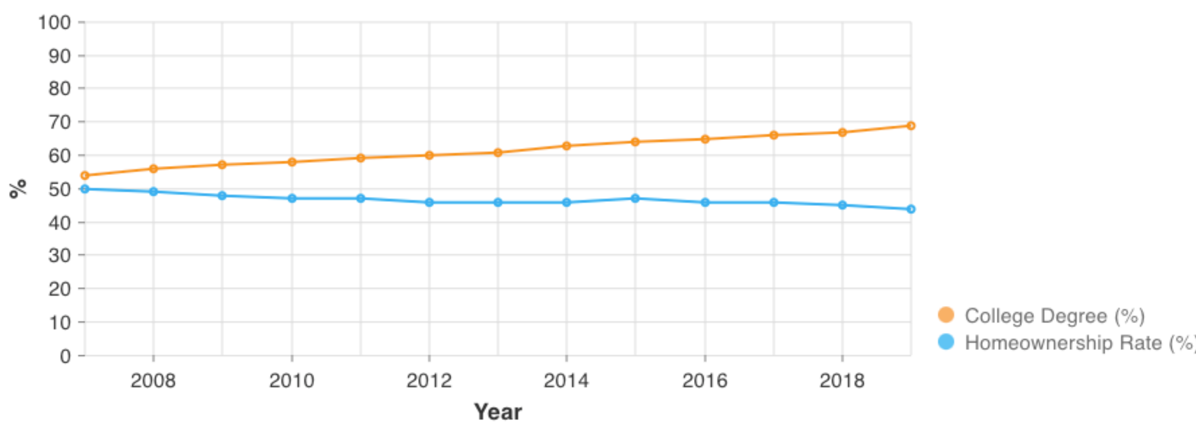
[18] https://www.seattletimes.com/seattle-news/data/seattle-ended-decade-with-faster-growth-than-suburbs-reversing-a-100-year-trend/

Figure 6. Rooms, vehicles per household, and household size trends over time (Seattle)



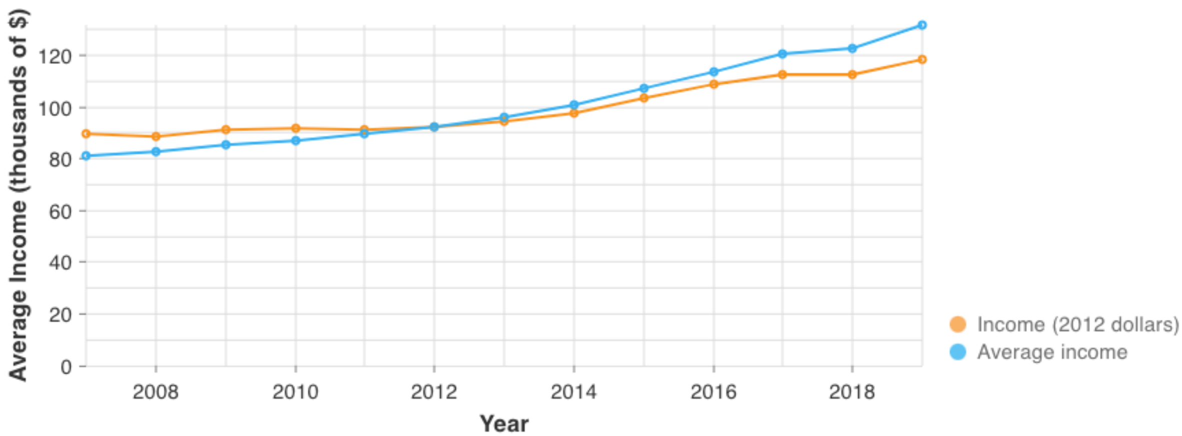
Since 2007, rooms per household, vehicles per household, and household size have remained largely constant.

Figure 7. Percent with college degree and homeownership rate trends (Seattle)



The share of households with a college degree has increased substantially, from 54% to 69%, while the home ownership rate has declined slightly, from 50% to 44%.

Figure 8. Income over time (Seattle)



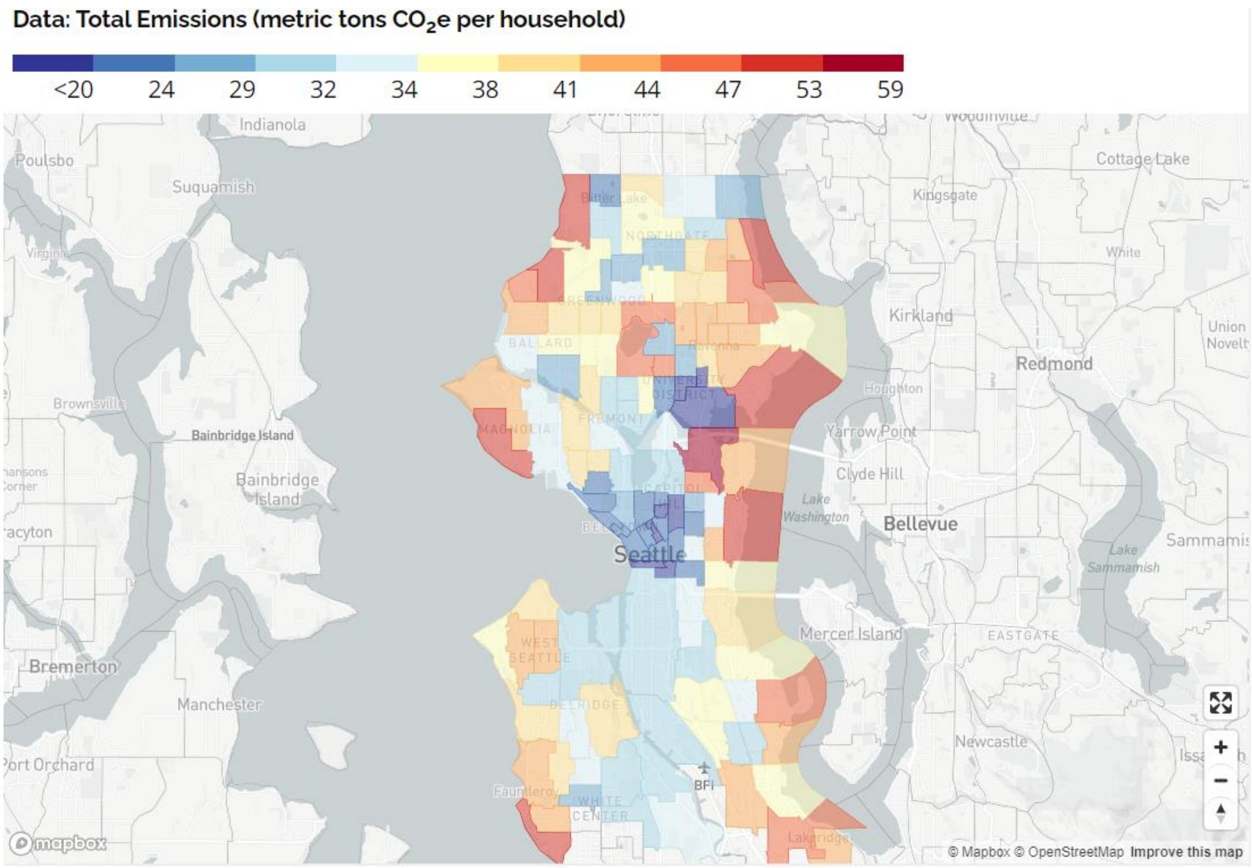
The biggest change overall, however, has been in income. Since 2007, household incomes have increased by over $50,000, or 62%. After adjusting for inflation, this is an increase of 33%.

Growing household incomes – well outpacing inflation – have kept Seattle's consumption-based emissions from declining over time. Seattle's commitment to using carbon-free electricity, however, along with an abundance of public transit and low vehicle usage, have meant that consumption-based emissions are still well below national averages on a per household and per capita basis.

Neighborhood Variation

Among the 135 neighborhoods or census tracts within the city, there is substantial variation in the key driving demographic variables and hence in consumption-based emissions (Figure 9). The highest-emitting neighborhood has per-household emissions of 59 $MTCO_2e$, while households in the lowest-emitting neighborhood have emissions of 17 $MTCO_2e$ – roughly a 3-fold difference.

Figure 9. Consumption-based emissions map ($MTCO_2e$ per household).



Consumption-based emissions were modeled on variables such as household size, income, and vehicle ownership as well as geography, climate, and other relevant data. How Seattle neighborhoods differ related to these variables, and estimated consumption-based emissions as a result, is driven by a wide range of historic and current conditions.[19] Land use zoning is a significant influence on consumption-based emissions. Zoning indicates where which types 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, downtown Seattle and other dense, mid and high-rise multifamily zoned areas tend to have the lowest emissions per household. The land use plans and historical development in downtown Seattle has resulted in taller buildings, closer together, with smaller homes which are typically available for rent.

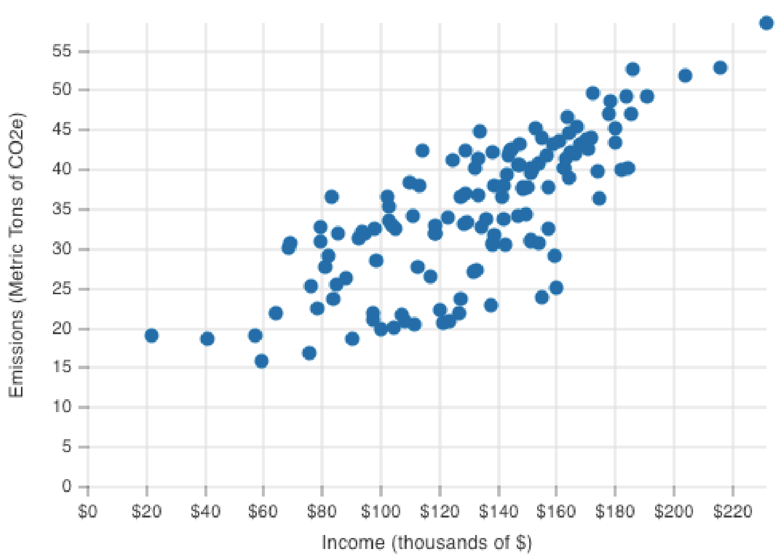
[19] For more detail about the variables and modeling process, see Appendix B: CBEI Modeling Approach: Model Input Variables.

Because more people and destinations are closer together, densely populated areas like downtown are often more walkable and have more public transit available, reducing vehicle ownership. Areas with high apartment-density have 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, less dense areas of the city with larger, detached homes take more energy to heat or cool, and the lack of nearby destinations generally results in greater automobile usage.

Today's consumption-based emission neighborhood rates also mirror historic redlining. Because of discriminatory lending practices, people of color – particularly Black, Hispanic/Latino, and Native Americans – were essentially unable to afford to buy a single-family home in Seattle's historically redlined neighborhoods. The neighborhoods delineated as "less desirable" and "hazardous" a hundred years ago up into the 1970s are still the more affordable areas today. As a result, Seattle's, and the U.S.'s in general, highest emission neighborhoods are also among the whitest and wealthiest.

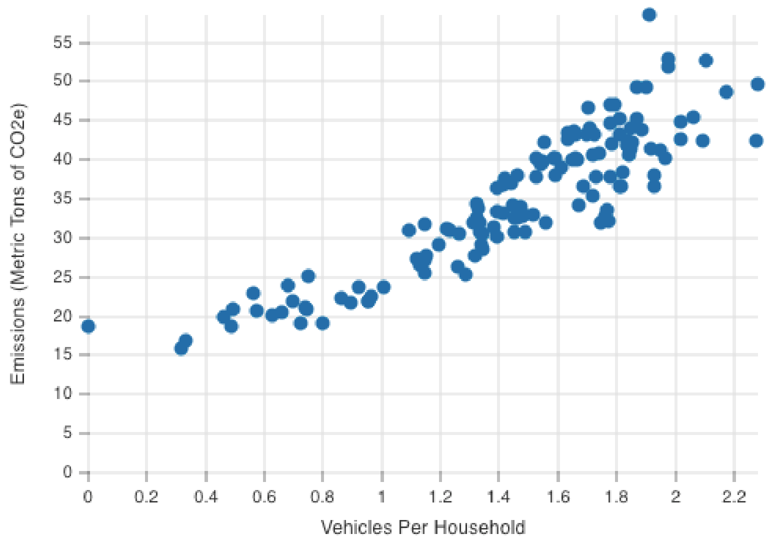
The following charts provide some examples of how these neighborhood demographics correlate with per household emissions across the city. Each scatterplot shows census tracts in the city, with a demographic variable – such as income, vehicles per household, rooms per household, and home ownership rate – on the horizontal axis, while average per-household emissions for each tract are plotted on the vertical axis.

Figure 10. Household income vs emissions by census tract.



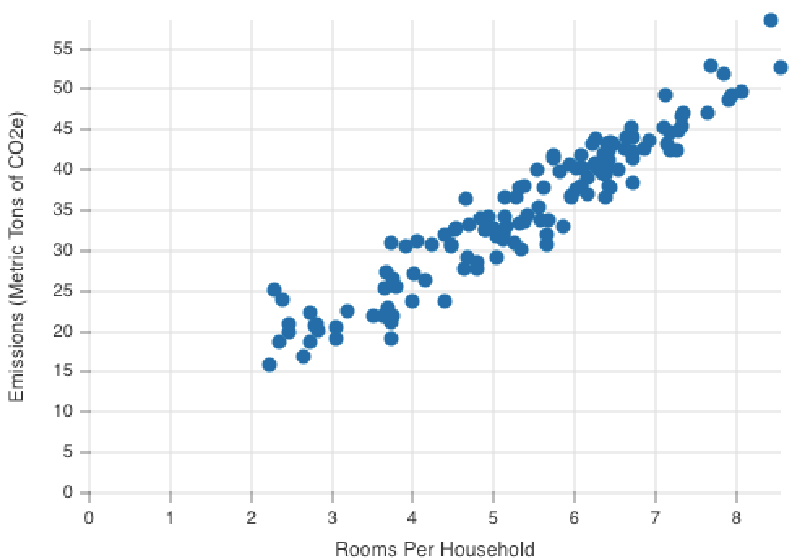
Higher incomes strongly correspond to greater consumption emissions. However, even at a given income level, different neighborhoods have different household emissions – sometimes by as much as a factor of 2. At the very highest incomes, neighborhoods tend to be clustered at the upper end of emissions, but middle-income (for the city) has a wider range of variation. Middle-income households often have the choice of either living in suburban, car-dependent communities or more walkable urban cores; those that live in areas with lower dependency on automobiles – as shown in the next chart – can have much lower emissions.

Figure 11. Vehicles per household vs emissions by census tract.



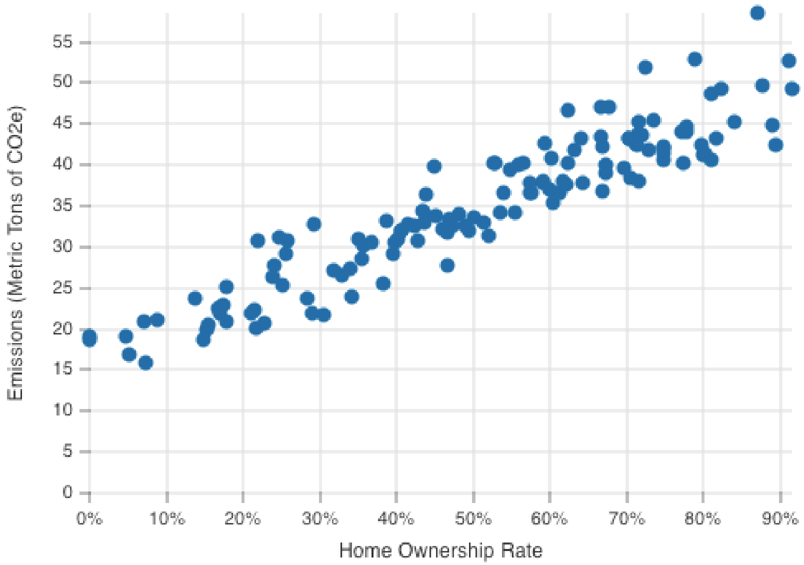
Greater vehicle ownership strongly corresponds to greater emissions, almost entirely due to the increased driving associated with the extra vehicle(s). Households with more vehicles may be wealthier, and thus able to afford the extra vehicle; but they may also be lower income and unable to afford a transit-rich city center, have jobs which are not adequately served by transit, or both.

Figure 12. Number of rooms per household vs emissions by census tract.



More rooms per home strongly corresponds to greater emissions – homes with more rooms take more energy to heat or cool and have more space to accommodate more purchases of furniture and other household goods.

Figure 13. Home ownership rate vs emissions by census tract.



Greater home ownership strongly corresponds to greater emissions. This is partly because home ownership correlates with income and household size, but it is also because home ownership on its own leads to more consumption of goods that are higher emissions – for instance, furniture and miscellaneous housewares.

Regional Comparison

Across Seattle, consumption-based household emissions range from 28 to 64 tons per household, with an average of 48 tons per household, or 18 tons per person. There is significant geographic variation, driven primarily by differences in income, household size, and vehicle ownership, reflective of different historical choices in local land use decisions and the availability of public transit.

Table 4 below compares consumption-based emissions between Seattle with King, Pierce, Kitsap, and Snohomish Counties, as well as the US average. Unless otherwise stated, all emissions are on a per-household basis.

Table 4. Regional CBEI comparison

Category		Seattle	King	Pierce	Kitsap	Snohomish	US AVG
Total Per Household Emissions		33	42	45	45	41	45
Total Per Capita Emissions		16	17	17	19	15	17
Per Household	Transportation Emissions	10.2	14.2	15.6	15.6	16.2	10.8
	Housing Emissions	3.1	6.0	9.2	9.5	3.5	9.5
	Food Emissions	7.9	8.4	8.0	8.1	8.4	9.5
	Goods Emissions	4.6	5.0	4.7	4.7	4.9	9.5
	Services Emissions	7.3	7.9	7.9	7.5	7.9	5.9

Seattle has the lowest per-household consumption-based emissions in the region and second lowest per capita. Seattle households are much more likely to be car-free or car-lite, reducing their transportation emissions; and Seattle City Light provides 100% carbon-free electricity to residents, reducing electricity emissions to almost zero. As a result, despite higher incomes than most other areas in the region, Seattle residents have among the lowest-emission lifestyle. Smaller household sizes also mean lower food consumption and associated emissions; however, smaller household sizes relative to income is also the reason that Seattle's per capita emissions are higher than those of neighboring Snohomish County.

The tract-level maps below show the household and per capita emissions across the four-county Puget Sound region.

Figure 14. Puget Sound neighborhood CBEI map ($MTCO_2e$ per household).

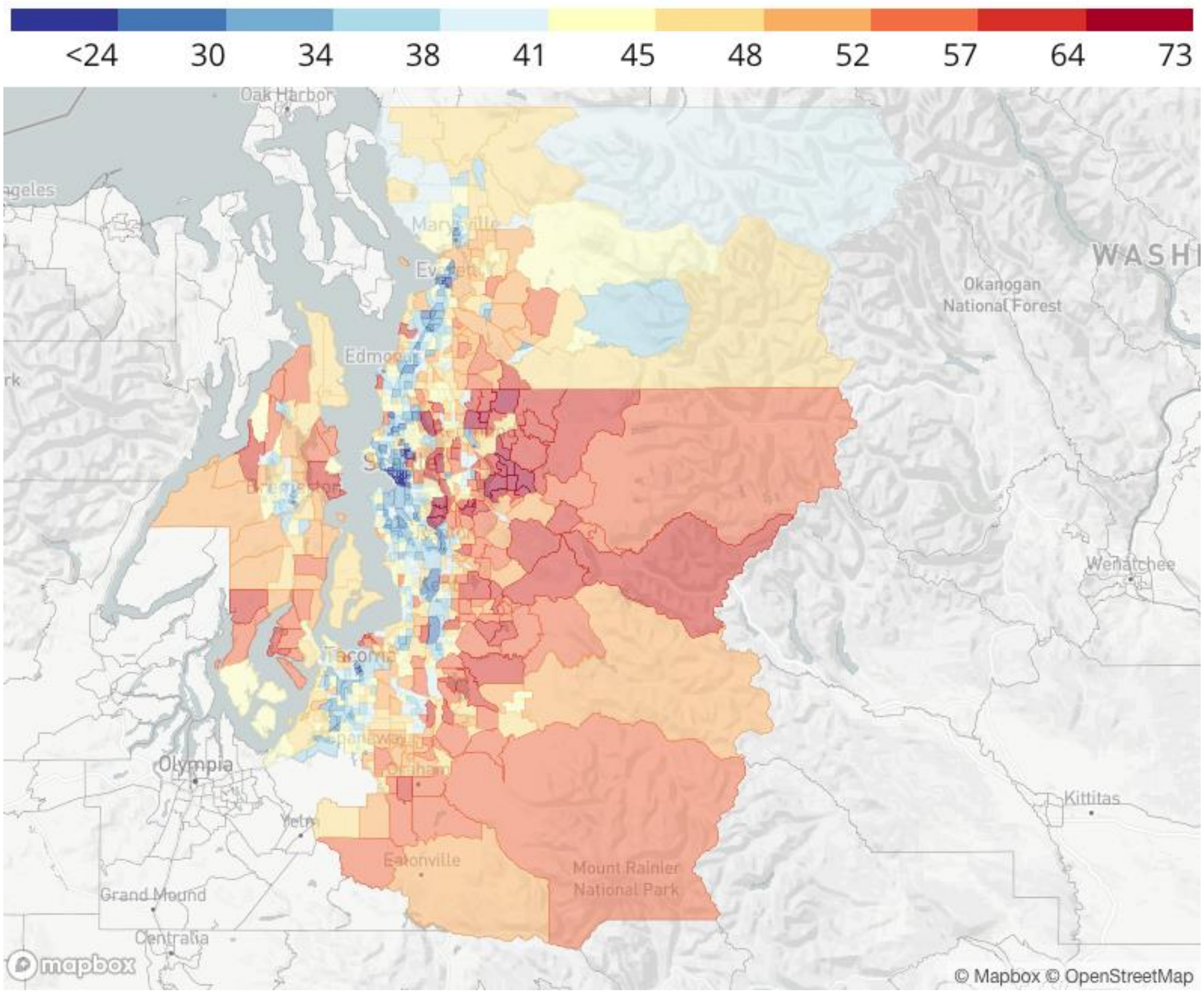
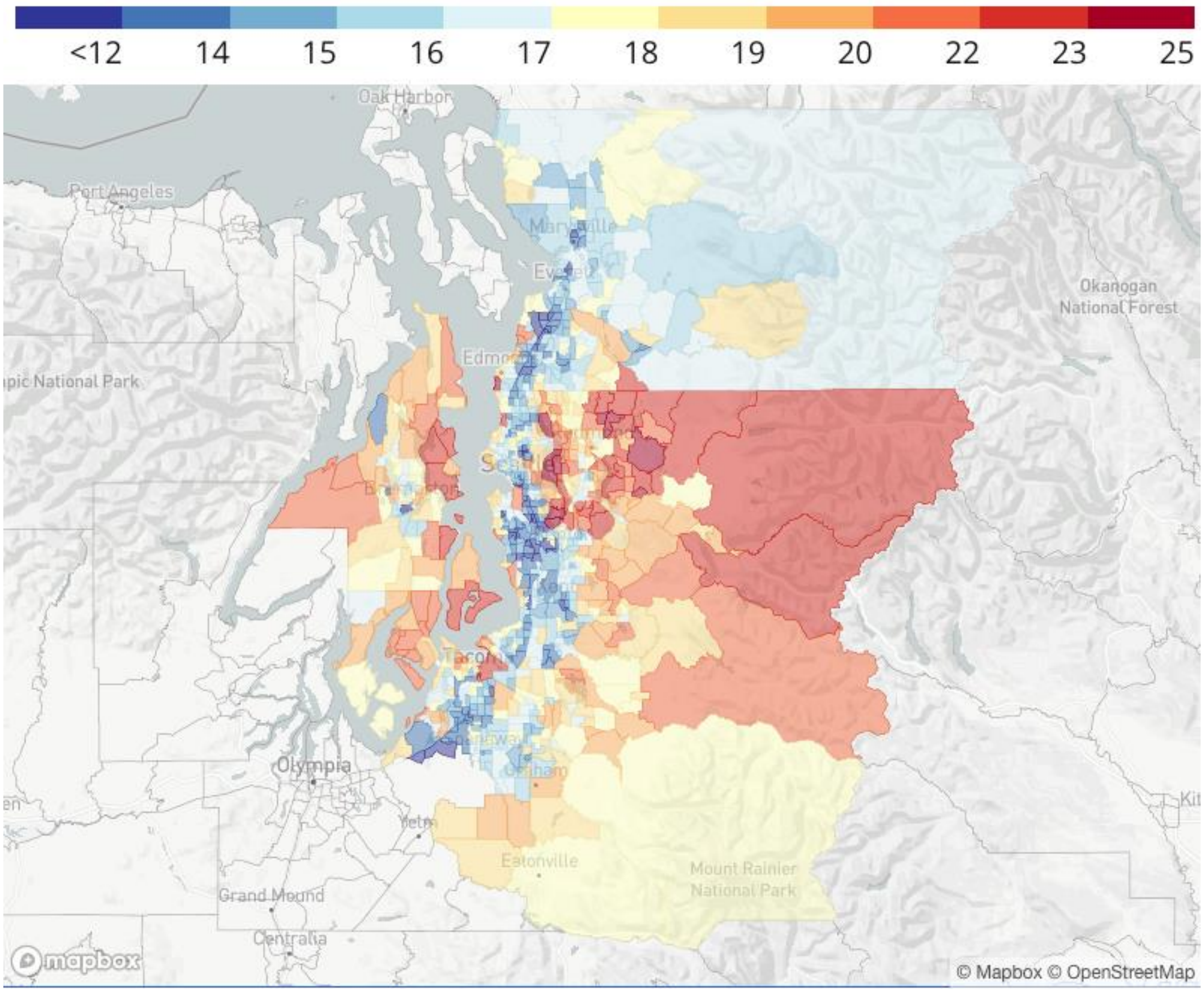


Figure 15. Puget Sound neighborhood CBEI map ($MTCO_2e$ per person).



Strategies to Address Consumption-Based Emissions

City of Seattle is committed to addressing consumption-based emissions, and this inventory is an important first step in understanding how to do so. Seattle has been an international leader in climate policy, solid waste management, water stewardship, and resource conservation for decades, thanks to public support for environmentally-focused programs and thoughtful planning. Under the framework of the One Seattle Climate Justice Agenda, Seattle is investing to support policies and programs aimed at building an equitable clean energy economy, ensuring a just transition away from fossil fuels, and building healthy and climate resilient communities. Seattle is also building toward an inclusive circular economy, where all materials, water, and resources are valued, and nothing is wasted.

The inventory highlights the continued importance of our efforts around transitioning away from fossil fuels in our transportation and buildings, and shines a light on the opportunity to reduce greenhouse gas emissions from the food we eat, the things we buy, and the materials that go into building our homes. This inventory helps inform and prioritize our existing climate programming and policies and will initiate further exploration on ways that the city should be addressing consumption-based emissions.

In general terms, there are three ways to reduce consumption-based emissions:

- **Shift consumption to lower-carbon alternatives**. Consumption-based emissions can be reduced by shifting consumption to lower-carbon alternatives. Introducing more plant-based foods in diets (as opposed to meat and dairy consumption) for example, could significantly reduce the carbon footprint of many households. Likewise, using lower-carbon cement blends in housing construction can lower the carbon intensity of residential buildings.
- **Reducing waste and rethinking consumption**. Consumption-based emissions can also be reduced by addressing waste and rethinking how we consume. This can be be achieved by reducing waste (e.g., by planning meals and buying only the food one needs); greater efficiency (e.g., using energy-efficient vehicles and appliances); sharing or renting goods, like tools, cars, or gardening equipment; and, when purchasing goods, purchasing ones with greater reusability and durability (e.g., avoiding “fast fashion” clothing). These kinds of changes can be encouraged through various “circular economy” measures that, for example, incentivize more durable and reusable product designs and promote more sustainable consumption habits (Haigh et al. 2021).
- **Lowering the carbon intensity of supply chains.** Although consumption changes can significantly reduce emissions, they will ultimately need to be complemented by measures that reduce emissions associated with the production, provision, and/or delivery of energy, transportation, food, goods, and services. A wide range of interventions are possible here, including measures to reduce *supply chain* waste (before delivery to households) and to decarbonize production methods. It is critical for governments to collaborate with the private sector in order to mobilize change in this area.

To address consumption-based emissions and to advance Seattle’s vision of zero waste, we support and promote policies and practices that reduce Seattle’s waste and carbon pollution as rapidly as possible (e.g., electrification, food waste prevention and food rescue, building deconstruction and building materials salvage, promotion of reuse and repair).

There are a number of specific initiatives led by the City of Seattle to address the consumption-based emissions identified in this CBEI including:

(1) Gasoline Consumption

The City of Seattle encourages Clean Transportation and a shift away from private vehicle use (and the associated consumption based emissions) by (i) encouraging mode shift (investing in zero carbon transportation options including public transportation, biking, and walking) (ii) electrifying personal and commercial vehicles & ensuring the electrical grid is ready for transportation electrification with goals outlined in the Transportation Electrification Blueprint. Seattle's 2035 comprehensive plan will reducing automobile trips through transit, walking, biking, rolling, and creating transit-oriented neighborhoods.In addition, Mayor Harrell recently issued an executive order to direct City departments to accelerate climate investments and innovation for the transportation system.

(2) Fossil Gas Usage

Emissions resulting from the burning of fossil fuels like fracked gas for heat, hot water, and appliances.These emissions pollute our air and accelerate climate change, which disproportionately harms Seattle's Black, Indigenous, and People of Color (BIPOC) communities. For our health and resilience in the face of a changing climate, Seattle is committed to eliminating climate pollution and transitioning to 100% clean energy in our buildings by 2050.

Seattle's Clean Heat Program offers funding for low-income homeowners to convert oil furnaces to an electric heating system at no cost to them, and rebates available for non low-income homeowners, lowering both their carbon footprint and energy costs as a result. The Office of Housing also offers a HomeWse Weatherization Program that provides free energy efficiency improvements to qualified homes. Seattle's Office of Sustainability & Environment is additionally in the process of developing legislation for carbon-based building performance standards for existing commercial and multifamily buildings 20,000 sq. ft. or larger. The standards Seattle is considering would phase-in and get more stringent over time to net-zero by 2050. To lead by example, Seattle is transitioning its City-owned buildings off fossil fuels by 2035.

(3) Shelter

To reduce the landfilling of materials used for buildings and encourage reuse of these same materials, Seattle requires building salvage assessments for all demolition projects and larger alterations projects. In addition, the City bans specific recyclable building materials from being landfilled.

Seattle's Priority Green Expedited Permitting shortens the time it takes for projects to get a construction permit in exchange for meeting a green building certification and other criteria. The program requires information on a building's embodied carbon to qualify, encouraging developers to explore opportunities to reduce waste and save embodied carbon by retaining or deconstructing existing structures, and exploring opportunities to reduce embodied carbon from building materials by using and advocating for environmental product declarations.

(4) Food

Seattle Public Utilities' Love Food, Stop Waste program provides consumers with information and tools to help reduce food waste at home. As a signatory of the Pacific Coast Food Waste Commitment, SPU is collaborating with food businesses such as grocery retailers and manufacturers to reduce food going to garbage across the West Coast by 50% by 2030. In addition, SPU is partnering with businesses and nonprofits to improve how edible, unsold food gets donated to those that need it in Seattle and diverted from the organics or garbage streams.

Seattle's Food Action Plan outlines strategic priorities to (i) Prevent food waste, rescue (redistribute) surplus food for people who need it and compost the rest into new natural resources and (ii) Reduce climate pollution associated with Seattle's food system and support food production that improves the environment.

(5) Goods & Services

Seattle is increasingly focusing on waste prevention strategies and metrics in solid waste programs and policies. To prevent waste, which is proven to lead to the best results in terms of reducing pollution and resource use, Seattle is looking "upstream" at how products and packaging are made for opportunities to prevent or reduce waste from the start.

Seattle's 2022 Solid Waste Plan Update: Moving Upstream *to Zero Waste* and SPU's Strategic Business Plan identifies the creation of an inclusive and circular economy as a strategic priority. SPU's upcoming Waste Prevention Strategic Plan will further identify areas of focus to prevent waste, and therefore reduce consumption-based emissions across multiple sectors.

SPU runs a Waste Free Communities Matching Grant program and is a partner to the Seattle Good Business Network's PreCycle Innovation Challenge and NextCycle Washington, supporting the burgeoning community of businesses, community organizations, and individuals that are building the circular economy in Seattle and supporting efforts such as reuse, repair, and sharing. In addition, SPU is developing an innovative investment program, *Seeds of Resilience,* that provides initial seed funding to incubate and accelerate projects that advance the utility's one water, zero waste, community centered vision.

SPU has formed a public-private partnership to create the first standardized, city-wide reusable food and beverage container system, Reuse Seattle. Its goal is to make food and beverage container reuse scalable and affordable for consumers, businesses, and the city.

Seattle passed some of the first local ordinances banning EPS foam foodservice ware and single-use plastic bags. Seattle requires that all shopping bags, foodservice containers, and utensils be reusable, recyclable, or compostable, with limited exemptions. Seattle continues to advocate for producer responsibility for packaging and paper products, the right to repair, and post-consumer recycled content minimum requirements.

(6) Water

SPU is committed to water conservation and partners with our customers to protect this important resource through our regional water conservation program, the Saving Water Partnership. SPU is laying the groundwork to support voluntary action by the private sector to advance more widespread adoption of on-site non-potable water reuse systems, which are systems that allow us to recapture, clean, and reuse water all within the footprint of one or more buildings. In 2021, the Washington State Legislature passed a bill requiring the Washington State Department of Health to develop statewide rules for the use of on-site non-potable water reuse systems. and SPU is positioning the utility to partner with other public sector agencies and private sector partners to advance this work once the rules are finalized.

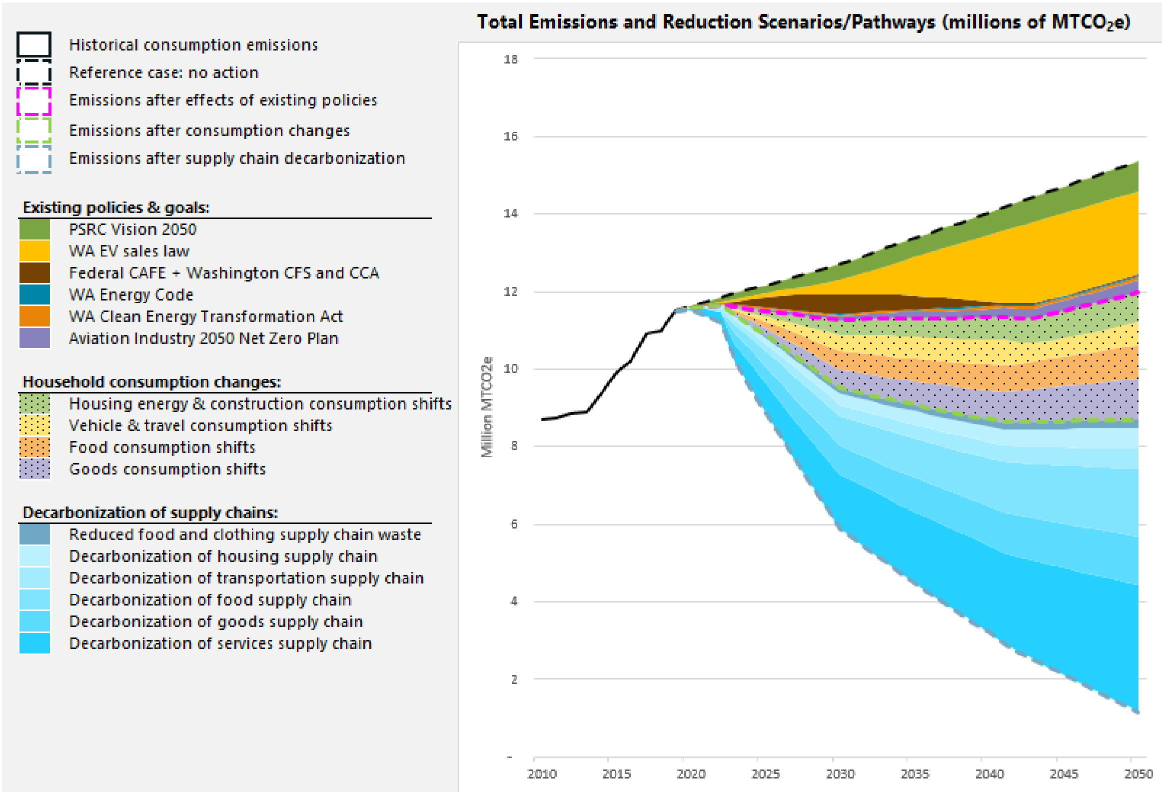
The Household Consumption-Based Emissions Abatement Analysis Tool

While Seattle has already made significant progress to address consumption-based emissions and has supportive programing and policies in place, there are a number of areas that should be further examined in order to tackle our consumption-based emissions.

The PSREA (Puget Sound Regional Emissions Analysis) Consumption-Based Emissions Abatement Analysis (CBEA) tool, developed by the Stockholm Environment Institute, shows how a combination of existing policies household consumption changes, and broader economy-wide decarbonization efforts. The tool allows exploration of different kinds of abatement *wedges*, i.e., reductions in consumption-based emissions from discrete measures that, when added together, could move the region towards its goals. These are illustrated in a *wedge diagram* showing the contribution of different measures to total greenhouse gas abatement (Figure 16).

In the CBEA tool, all emission reductions are measured against a *reference case*, indicated by the dotted black line in Figure 16. As in the PSREA territorial abatement wedge analysis, the reference case is a projection of how emissions in the Puget Sound region will grow along with population growth, assuming *no other changes* in the consumption behavior or carbon footprints of area households. This is a simplification. Under a true “business as usual” scenario with no abatement measures, for example, consumption-based emissions per household are likely to change, due to changes in household consumption patterns (e.g., arising from changes in income and the relative prices of goods and services) and the economy (e.g., switching to different production methods as technologies evolve). Like the geographic wedge analysis, the CBEA tool is meant to illustrate the *relative magnitude* of different abatement wedges over time, compared to today’s consumption and technologies, not estimate absolute emission reductions against a true “business as usual” forecast.

Figure 16. CBEA wedge diagram showing the contribution of different abatement measures for Seattle



The CBEA tool defines multiple abatement wedges related to all three of these general strategies. In the tool's summary wedge diagram (illustrated in Figure 16), abatement wedges are grouped into three kinds of interventions:

- *Existing policies and goals*. These wedges are shown between the reference case and the pink dotted line in Figure 16.
- *Household consumption changes*. These wedges are shown between the pink and green dotted lines in Figure 16.
- *Decarbonizing supply chains*. These wedges are shown between the green and grey dotted lines in Figure 16.

Each of these is explained further below.

Existing Policies and Goals

A range of existing policies and goals – at local, state, national, and international levels – can be expected to reduce Puget Sound household consumption-based emissions relative to the reference case. These include many of the same policies whose effects are estimated in the PSREA geographic wedge analysis. For the consumption-based analysis, they include:

- Federal vehicle fuel efficiency (CAFE) standards
- Washington State clean energy, clean fuel, energy efficiency, electric vehicle, and carbon pricing policies

- Puget Sound Regional Council plans for reducing average household passenger car travel
- International aviation industry goals for reducing air travel greenhouse gas emissions

Under the CBEA tool's default assumptions, existing policies and goals are estimated to reduce Seattle household consumption-based emissions by 22% in 2050, relative to the reference case.

Rethinking Consumption

Although existing policies will help to reduce consumption-based emissions, there is much more that local households can do to change their consumption of energy, housing, transportation, food, and goods in ways that would substantially reduce their carbon footprints. Consumption-based emissions can be reduced by shifting consumption to lower-carbon alternatives. Introducing more plant-based foods in diets, for example, could significantly reduce the carbon footprint of many households. Likewise, using lower-carbon cement blends in housing construction can lower the carbon intensity of housing. Consumption-based emissions can also be reduced by addressing waste and rethinking how we consume. This can be achieved by reducing waste (e.g., throwing away less food so less needs to be produced); greater efficiency (e.g., using energy-efficient cars and appliances); sharing or renting goods, like tools, cars, or gardening equipment; and purchasing goods with greater reusability and durability (e.g., avoiding "fast fashion" clothing). These kinds of changes can be encouraged through various "circular economy" measures that, for example, incentivize more durable and reusable product designs and promote more sustainable consumption habits (Haigh et al. 2021).

New local policies could help encourage these shifts and realizing their full potential will require collaboration amongst the private sector, public sector, and residents.

Under the CBEA tool's default assumptions, these additional shifts in consumption could reduce Seattle household carbon footprints by an additional 21% in 2050, relative to the reference case.

Decarbonizing National and Global Supply Chains

When it comes to reducing consumption-based emissions, Puget Sound residents will not be able to do the job alone. Locally consumed goods and services depend on supply chains that extend well beyond the region, to other states and around the world. To achieve the Paris Agreement's goal of keeping global warming "well below 2^{o}C," the world will need to fully "decarbonize." That is, goods and services will need to be produced and transported using carbon-free energy sources; chemicals, plastics, and pharmaceuticals will need to be derived from fossil fuel alternatives; fossil carbon emissions will need to be captured and stored in geologic reservoirs where they cannot be avoided; and other greenhouse gas emissions will need to be dramatically reduced, including methane and nitrous oxide in the agriculture sector.

The task of decarbonizing the economy will require systemic transformations in how energy, goods, and services are produced, including wholesale adoption of carbon-free energy sources, but also dramatic improvements in energy efficiency and more efficient use of materials in the production of things like housing and consumer goods. The tool highlights a couple of areas where reducing *supply chain* waste could significantly reduce consumption-based emissions: for food and clothing (see Figure 16, grey wedge). For other goods and services, economy-wide efforts to decarbonize energy, improve energy efficiency, and use materials more efficiently are represented as "supply chain decarbonization" wedges. As a default, these wedges indicate how much the Puget Sound's consumption-based emissions would be reduced if the *rest of the world* were to decarbonize in line with Washington State's greenhouse gas reduction targets. Legislative targets established in 2020 require economy-wide emission reductions of 45% below 1990 levels by 2030, 70% below 1990 levels by 2040, and net zero emissions by 2050 (Washington State Department of Commerce 2020). Though ambitious, these targets are in line with what is needed globally to avoid more than 1.5ºC of warming.

The tool also allows the selection of alternative scenarios based on modeling by the International Energy Agency (IEA 2021):

- **IEA Net Zero**. Expected decarbonization of energy, goods, and services in line with the IEA's roadmap for achieving "net zero" energy-sector emissions worldwide by 2050. This scenario is similar to the pathway reflected in Washington State's greenhouse gas targets.
- **Current policies (US)**. Expected decarbonization of energy, goods, and services in line with the IEA's modeling of the effects of current US climate and energy policies. This reflects the emission reductions that could be expected if one assumes (most) goods and services consumed in the Puget Sound region are produced in the United States.
- **Current Policies (Global)**. Expected decarbonization of energy, goods, and services in line with the IEA's modeling of the effects of current climate and energy policies around the world. This reflects the emission reductions that could be expected if one assumes (most) goods and services consumed in the Puget Sound region are produced in other countries.

Finally, getting to net zero globally will also require reducing greenhouse gas emissions from land use and agriculture. These are an important component of consumption-based emissions for food and, to a lesser extent, clothing and textiles. The tool addresses these emissions in separate wedges associated with: (1) halving nitrous oxide emissions from the application of fertilizer, and (2) substantially reducing methane emissions from livestock. (In the summary wedge diagram – Figure 16 – these wedges are not shown separately, but instead are included under the "supply chain decarbonization" wedges for food and goods.)

Under the CBEA tool's default assumptions, supply chain decarbonization measures are assumed to follow Washington State greenhouse gas reduction targets and could reduce Seattle household carbon footprints by an additional 49% in 2050, relative to the reference case.

Note that if all assumed abatement wedges are applied, emissions are projected to be 95% lower in 2050 than they would be in the reference case. The remaining 5% of emissions come primarily from unabated emissions in the agriculture and aviation sectors.

Seattle has multiple paths available to reducing consumption-based emissions, as outlined above. Seattle is committed to mitigating climate impacts using a comprehensive approach. Actions that reduce consumption-based emissions will also offer direct benefits to Seattle's local economy, community resilience, and public health. Ultimately, the effort to address consumption-based emissions will require collaboration between residents, community, businesses, and the public sector, as locally consumed goods and services depend on supply chains that extend well beyond the region, to other states and around the world.

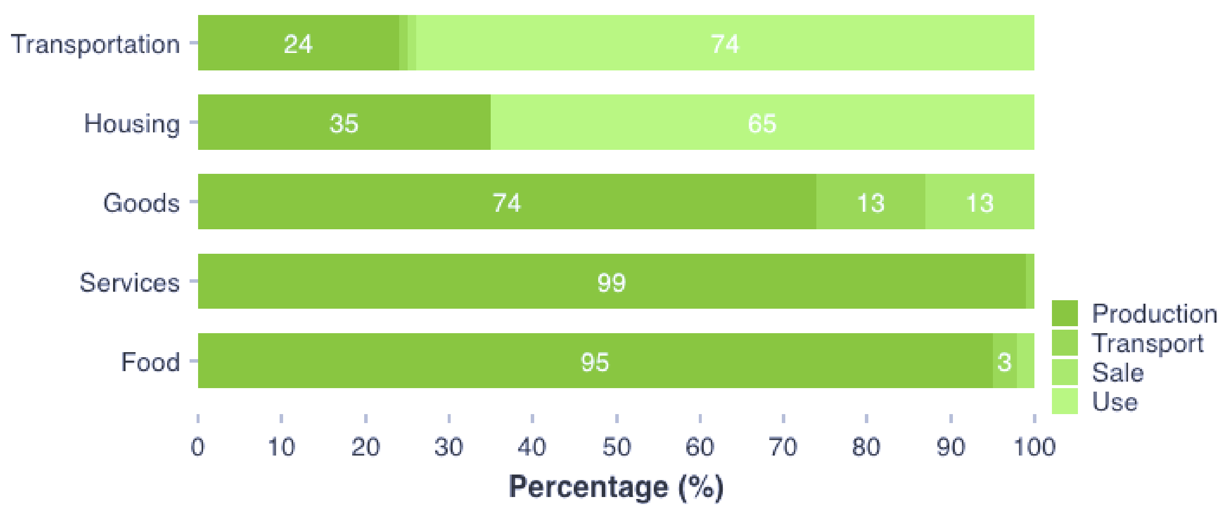
Appendix A: Emissions Breakdown by Supply Chain Stage

Consumption-based emissions occur at many points in 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. 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, they are not included on this chart).

Household Emissions Breakdown by Supply Chain Stage – US Average

Below, Figure 17 shows what percentage of emissions are associated with each life-cycle phase (production, transport, sale, and use), for each category of consumption.

Figure 17. Household emissions breakdown by supply chain stage – US average.



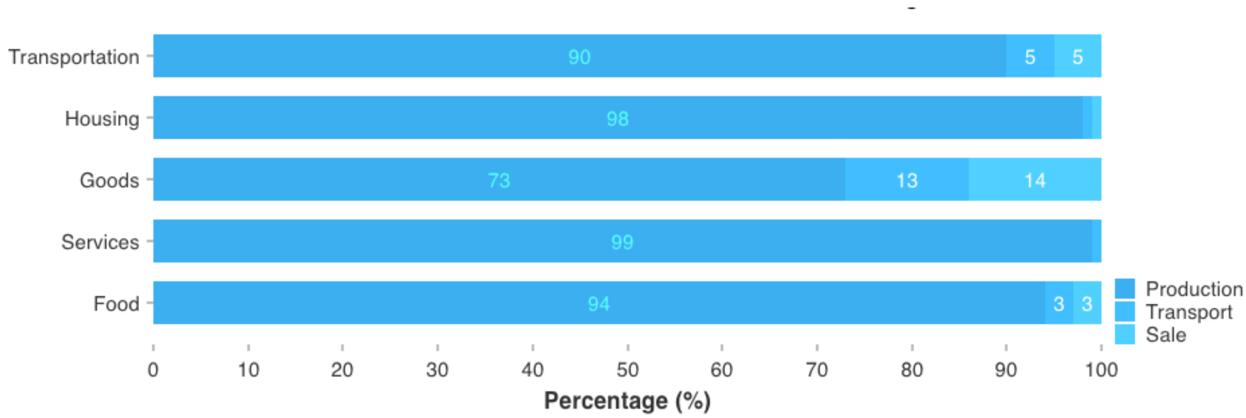
Overall, emissions from transportation and housing are dominated by "use phase" emissions – the burning of fossil fuels (such as gasoline or the methane in natural gas) for transportation or home heating energy. This "use phase" – primarily gasoline combustion – makes up nearly 74% of household transportation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

For food, goods, and services, however, 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.

Pre-Consumer Emissions Breakdown – US Average

Below, Figure 18 shows what percentage of emissions are associated with each life-cycle phase prior to use (production, transport, and sale), for each category of consumption. These are the emissions associated with the production of goods and services prior to households acquiring them.

Figure 18. Pre-consumer emissions breakdown – US average.



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% 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 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).

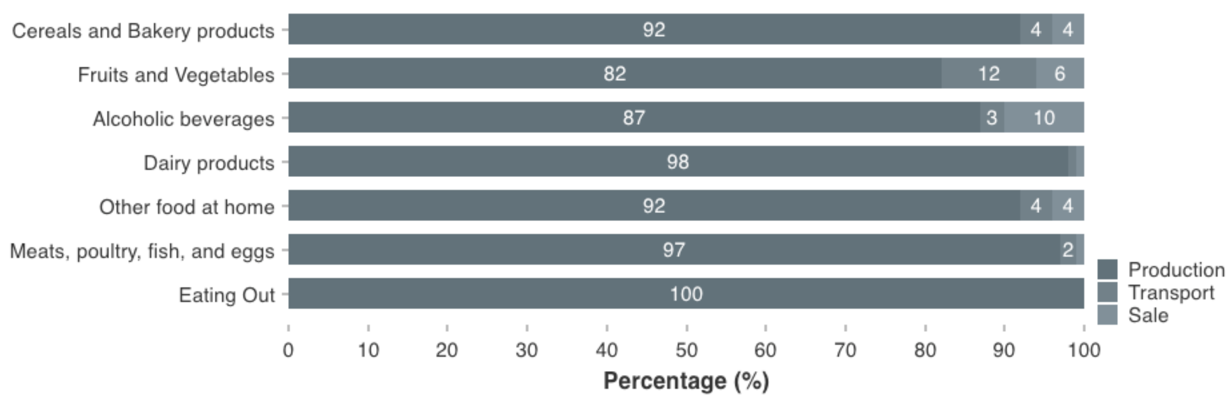
Like Housing, pre-consumer emissions from Services are overwhelmingly (99%+) from production. Services is primarily made up of activities like healthcare, education, entertainment, and various financial services; most of these involve little to no retail or transportation to provide these services.

Lastly, for Food, roughly 95% of emissions occur in production. As discussed in the Food category breakdown, 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. The following chart provides a detailed breakdown by sub-category within Food.

Pre-Consumer Food Emissions Breakdown – US Average

Below, Figure 19 shows what percentage of emissions are associated with production, transport, and sale, for each category of food.

Figure 19. 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, 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, transportation emissions are overwhelmingly dominated by truck transport.

As discussed previously, meat and dairy products have significantly higher emissions (on either 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, even 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 B: CBEI Modeling Approach

The consumption-based emissions inventory (CBEI) is not a direct measurement of individual resident's consumption or behavior. Instead, EcoDataLab uses a model (a series of complex calculations) to estimate consumption and emissions, using a combination of real-world consumption or emissions data where available, along with predictions based upon household characteristics, as well as regional and national averages.

This model is based upon an approach first developed by the CoolClimate Network at the University of California, Berkeley, and published extensively in multiple scientific journals.

The overall model has a number of sub-models, but each one follows the same general formula:
1) Select a survey

We select a nation-wide survey, conducted by the US federal government, that focuses on an important element of the inventory. 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. CEX provides data used to model all categories of consumption except for gasoline and home energy use. NHTS provides data for the vehicle miles traveled model (which translates into gasoline usage), and RECS provides data for the home energy use models (including electricity, natural gas, and other heating fuels).

2) Identify key household characteristics

Next, we look at the household characteristics available from the survey, and identify data for which we can get nationwide data from the US census and other data sources. These data include variables like household size, income, vehicle ownership, etc. We also include geography, climate, and other relevant data where applicable.

3) Build a predictive model

Using the nation-wide survey and selected household and geographic characteristics, we run a computer program that identifies how strongly each of those household characteristics correlates 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 gives us 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. All EcoDataLab sub-models use at least six variables (…x_6), with some using a dozen or more to get the most accurate prediction possible.

In addition, many of the values we are considering 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 2 is typically two adults, whereas a household of 3 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

With these multiple linear regression models built (see above), we then collect over 200 points of local data - mostly census and climate data, from federal sources including the US Census Bureau, the National Oceanic and Atmospheric Administration (NOAA), but also 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, 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.

5) Make final adjustments to consumption estimates

While the multiple linear regression model helps us estimate consumption, the model doesn't perfectly resemble reality. We adjust for these discrepancies 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, we compare the model results 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, we use the real-world data in place of the modeled data; otherwise, we run the model at a geographic level at which data is available and use that to create a scaling factor, which we use to correct the locally modeled data. For example, the standard approach to energy modeling is to compare modeled state-level energy use with real-world state-level energy data, and then use that scaling factor to adjust a city or county's modeled energy use.

6) Calculate emissions

After calculating consumption using the models, we then calculate emissions. Most consumption emissions are calculated using the US EPA's USEEIO Model, which bridges the gap between consumption (dollars) and emissions ($MTCO_2e$). This model includes data on emissions by sector and supply chain stage, allowing us to differentiate 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.

For electricity emissions, we use EIA's 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.), we use the latest IPCC GWP values and best available academic literature to estimate life-cycle emissions. This includes fugitive and non-CO_2 GHG emissions, as well as any radiative forcing effects from other emissions (such as particulate matter or contrails).

When working with local jurisdictions, we always replace these national or grid average emission factors with the best available local data. We contact state agencies to procure detailed vehicle registration data, which we combine with US DOE fuel economy data to get the most granular and accurate estimate for fuel economy of local residents' vehicles. We work with local jurisdictions to identify local utilities and their geographic coverage, and their local emission factors for electricity, water & wastewater, or methane leakage rates. For waste emissions analyses, we use local household waste data where available, and either local emission factors or the US EPA WARM model.

Model Input Variables

The consumption models use the following six variables: household size, average income, vehicle ownership, home ownership, share of households 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 race of households (white, Hispanic or Latino, or neither) also proved to be statistically significant and was included.

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.

Capital Project Emissions

Emissions from construction of non-residential buildings and infrastructure are considered "fixed capital" emissions. These emissions are incorporated into the emission factors for the consumption of all goods and services.

Like with all consumption-based emissions, the CBEI considers emissions from construction that may occur anywhere in the world. As a result, even a jurisdiction which halted all construction and infrastructure maintenance would still have consumption-based emissions associated with construction occurring elsewhere in the world. A separate type of analysis could be conducted to specifically review local data on building construction and estimate Scope 3 emissions associated with that activity, but it would not be a household consumption-based approach because such an analysis would evaluate all emissions associated with construction, not just the share of emissions attributable to local residents' use of the infrastructure or facility.

Appendix C: Government Emissions

In the consumption-based inventory, government agencies are considered final demand the same way households are, and so government emissions are not attributed directly to households. These emissions are not insignificant – based on GDP data and the same USEEIO emission factors discussed in Appendix B, federal, state, and local governments across the US had emissions totaling over 660 million $MTCO_2e$. Of this total, roughly 69% came from state & local governments, with the remaining 31% from the federal government split between defense (24%) and non-defense sectors (7%).

Like households, government emissions include transportation, buildings, food, and procurement of goods & services. Transportation emissions include the use of government vehicles, aircraft, trains and buses, police and firefighting vehicles, ambulances, 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. 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.

Embodied emissions from construction, including infrastructure, are also included. Roads, highways, and bridges all have large emissions associated with their construction. Governments also build and maintain local water supplies and resources, as well as some railway and public transit infrastructure, with additional emissions associated. Lastly, other purchases of food, goods and supplies, and services all have emissions associated with them as well.

Government consumption, and associated emissions, are not linked to particular household characteristics or activities in readily traceable ways. While some government activities can be linked to certain households – such as direct cash transfers for unemployment insurance or social security; and healthcare coverage through Medicare, Medicaid, or veteran's benefits – other government activities, like infrastructure construction and maintenance, national defense and public safety (police & fire), R&D spending, and parks maintenance cannot be readily and systematically assigned to households based on any discernable characteristics.

As a result, these emissions can only be effectively allocated to households on a flat average basis. If these emissions were allocated to households, it would be an average of 5.5 $MTCO_2e$ per household. For Seattle, this would work out to an additional 1.9 million $MTCO_2e$ citywide. These "hidden" emissions are not otherwise captured in the consumption-based emissions inventory, but still contribute to overall emissions nationally and globally.

Seattle is taking steps towards measuring and addressing the emissions associated with our government operations. Departments are conducting their own operational emissions inventories (e.g. Seattle Public Utilities, Seattle City Light) and some departments are also conducting inventories of the emissions associated with their purchasing and contracting (their government spending) – Seattle Public Utilities, Seattle City Light, and Seattle Parks & Recreation. Strategies to address these emissions include purchasing electric vehicles and retrofitting buildings to eliminate natural gas usage, and developing sustainable procurement policies

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