King County Greenhouse Gas Emissions Inventory

A 2015 Update

December 2017

Prepared for King County, Washington

CASCADIA CONSULTING GROUP

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Acronyms

BOD	Biochemical oxygen demand (a metric of the effectiveness of wastewater treatment plants)
EIA	United States Energy Information Association
EPA	United States Environmental Protection Agency
CO_2e	Carbon dioxide equivalents
GHG	Greenhouse gas (limited to CO_2, CH_4, N_2O, and fugitive gases in this inventory
$MgCO_2e$	Megagrams of carbon dioxide equivalent
MOVES	Motor Vehicle Emission Simulator model (developed by EPA to quantify emissions from mobile sources)
NONROAD	Part of MOVES model developed by EPA to quantify non-road mobile emissions
ODS	Ozone depleting substance
PSCAA	Puget Sound Clean Air Agency
PSE	Puget Sound Energy
PSRC	Puget Sound Regional Council
SCL	Seattle City Light
SPU	Seattle Public Utilities
TCR	The Climate Registry
USDA	United States Department of Agriculture
WARM	Waste Reduction Model (model developed by EPA to quantify solid waste emissions)
WSDOT	Washington Department of Transportation
VMT	Vehicle Miles Travelled

Introduction and Context

Greenhouse gas inventories allow communities to account for sources and quantities of GHG emissions generated by community activities. This report includes two distinct inventories: a "geographic-plus" inventory and a "consumption-based" inventory. The geographic-plus inventory estimates the annual GHG emissions released within community boundaries and due to community activities, such as energy consumption and waste disposal. The consumption-based inventory accounts for the GHG emissions associated with the goods and services consumed within the community.

Table 1. Inventory comparison.

Geographic-Plus	Consumption-based
Emissions associated with all activities that occur inside the county, "plus" all electricity GHG emissions, even if the electricity is generated outside King County.	Embodied emissions associated with production, transportation, use and disposal of goods, food, and services consumed in King County.

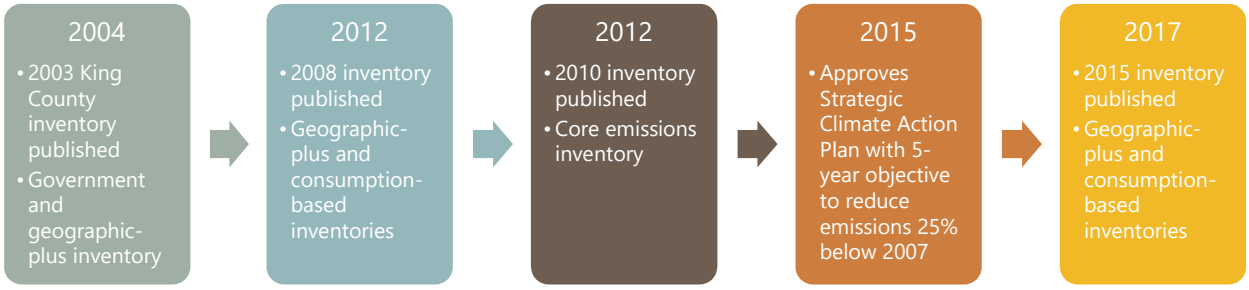
The **geographic-plus inventory** estimates GHG emissions produced by activities of the King County community, including emissions resulting from community energy use; wastewater and solid waste processing; and terrestrial carbon lost due to land use development. It includes both "in-boundary" emission *sources*—any physical process inside the jurisdictional boundary that releases GHG emissions—and activities resulting in GHG emissions. For example, it includes emissions associated with the in-county *production* of food and goods, regardless of where those goods are consumed, such as from a manufacturer located within King County that produces goods for export.

The **consumption-based inventory** provides an inventory of the GHG emissions associated with *consumption* of food and goods within the community, regardless of where the goods were produced. For example, the consumption-based inventory would not include GHG emissions associated with the production of goods from a local manufacturer that are consumed entirely outside the community, but would include GHG emissions associated with the production of goods manufactured in another community but consumed within King county. Thus, the consumption-based inventory accounts for different, but related sources of emissions associated with community activities.

The geographic-plus and consumption-based inventories provide insights about different GHG emission footprints of a community. For example, a community may consume electricity generated from low-emission sources, but also consume goods produced in another community with high-emission energy. The two inventories can account for these differences to paint a comprehensive picture of community emissions.

King County previously conducted geographic-plus inventories for 2003 and 2008 and a limited-scope "core" inventory in 2010 (Figure 1). This inventory report includes two major updates 1) a 2015 geographic-plus inventory that follows the U.S. Community Protocol and 2) updated 2003, 2008, and 2010 inventories that are compliant with the U.S. Community Protocol and comparable to the 2015 inventory.

Figure 1. King County greenhouse gas inventory timeline.



This report also presents a **contribution analysis** of the 2008 and 2015 geographic-based inventories, which explores drivers of King County emissions trends. The contribution analysis, conducted using a draft tool developed by ICLEI USA using a log-mean Divisia index (LMDI) decomposition approach, quantifies the impacts of a select set of drivers (e.g., weather, population growth, and utility fuel mix) on GHG inventories across two years, assuming no changes to operational or organizational boundaries.

This report is focused on assessing total countywide emissions and documenting and explaining what caused recent trends in countywide emissions. To learn more about what King County is doing to confront climate change and reduce emissions, please refer to King County's 2015 Strategic Climate Action Plan available at www.kingcounty.gov/climate.

Roadmap of this Report

This report is organized into the following three sections to assess GHG emissions associated with King County:

- A **Geographic-Plus Inventory** describes methodologies and results for the geographic-plus inventory.
- A **Contribution Analysis** section that explores drivers of King County emission trends.
- A **Consumption-Based Inventory** section presents methodologies and results from the consumption-based inventory.

The report concludes with sections that summarize **future considerations** for greenhouse gas emission quantification and reporting.

Geographic-Plus Inventory

The geographic-plus inventory quantifies the release of GHG emissions from activities within King County's geographic boundary, including from transportation, buildings, industrial processes, waste, water use, and agriculture. The "plus" portion expands this scope to include emissions produced by electricity generation outside of the community but consumed by in-county activities.

Results

OVERVIEW

- King County's geographic-plus greenhouse gas (GHG) emissions (Figure 2) totaled 20.3 million metric tons of carbon dioxide equivalent ($MgCO_2e$) in 2015. The geographic-plus inventory quantifies all emissions that physically occur in King County, plus emissions associated with electricity used in King County regardless of where it was produced.
- The largest sources of geographic-plus based GHG emissions were the built environment (62%), dominated by GHG emissions from residential and commercial energy usage (Figure 3), and transportation (36%), dominated by GHG emissions from passenger vehicles.
- 2015 geographic plus emissions increased by an estimated 0.9% compared to 2007[1]. This trend is not on track towards King County and Growth Management Planning Council (GMPC) adopted greenhouse gas (GHG) reduction targets that include a near term goal of a 25% reduction in countywide GHG emissions by 2020 compared to 2007.
- Per-person GHG emissions declined to 9.9 $MgCO_2e$ per person in 2015, an estimated 8.0% decrease compared to 2007. King County and GMPC targets include a per capita target of an 8.5 $MgCO_2e$ per person by 2020.
- Core emissions, which include emissions from residential and commercial electricity and natural gas, on-road vehicles, and solid waste, peaked in 2010 and have declined by 1.3% (203,000 $MgCO_2e$) overall and 7% per capita (0.6 $MgCO_2e$ per person).

[1] King County's comprehensive GHG inventories are for 2003, 2008 and 2015 calendar years. The baseline year for adopted local GHG emissions reduction targets is 2007, and this report interpolates 2007 totals based on 2003 and 2008 inventory data. Results in this report are compared to both 2007 and 2008 years; 2010 data are also available for "core" GHG emissions sources and are presented.

Figure 2. Sources of geographic-plus based GHG emissions for King County in 2015, excluding supplemental sources which are less than 1% of total emissions (total = 20.3 million $MgCO_2e$). The geographic-plus inventory includes emissions that occur in King County, plus electricity related emissions no matter where they occur.

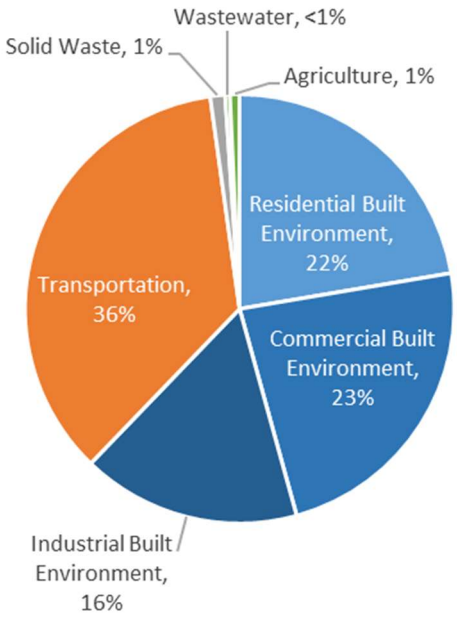


Figure 3. Sources of residential and commercial built environment GHG emissions for King County in 2015 (total = 9.3 million $MgCO_2e$).

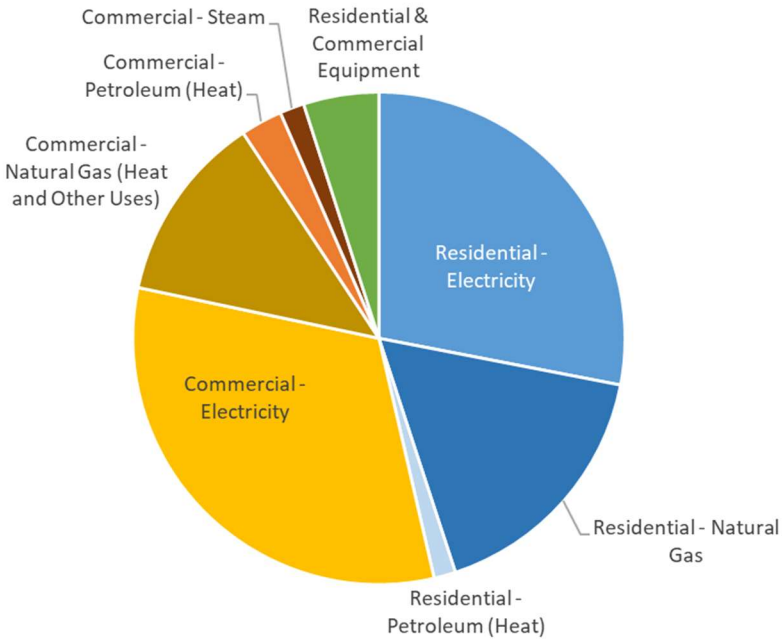


Figure 4. Core GHG emissions for King County over time.

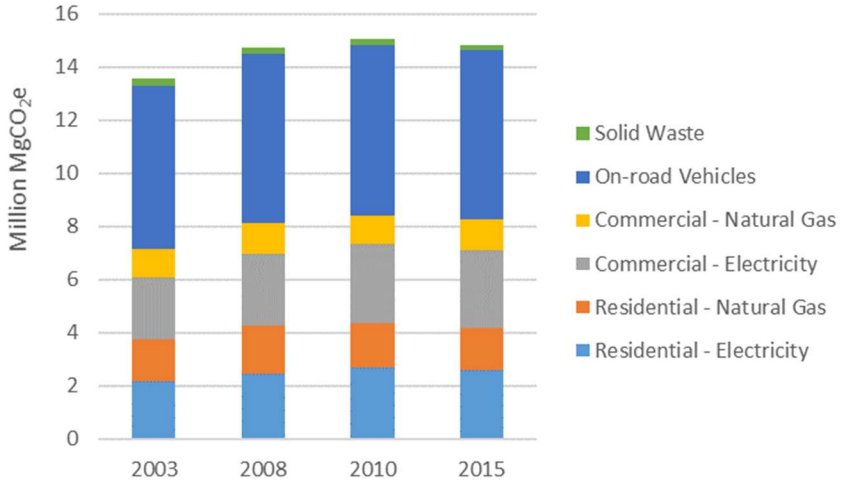


Figure 5. Geographic-plus GHG emissions by sector for King County. This chart shows trends in total GHG emissions in King County since 2003. The Contribution Analysis section of the report builds on this figure to document in a quantitative way which factors influenced trends in total emissions between 2008 and 2015.

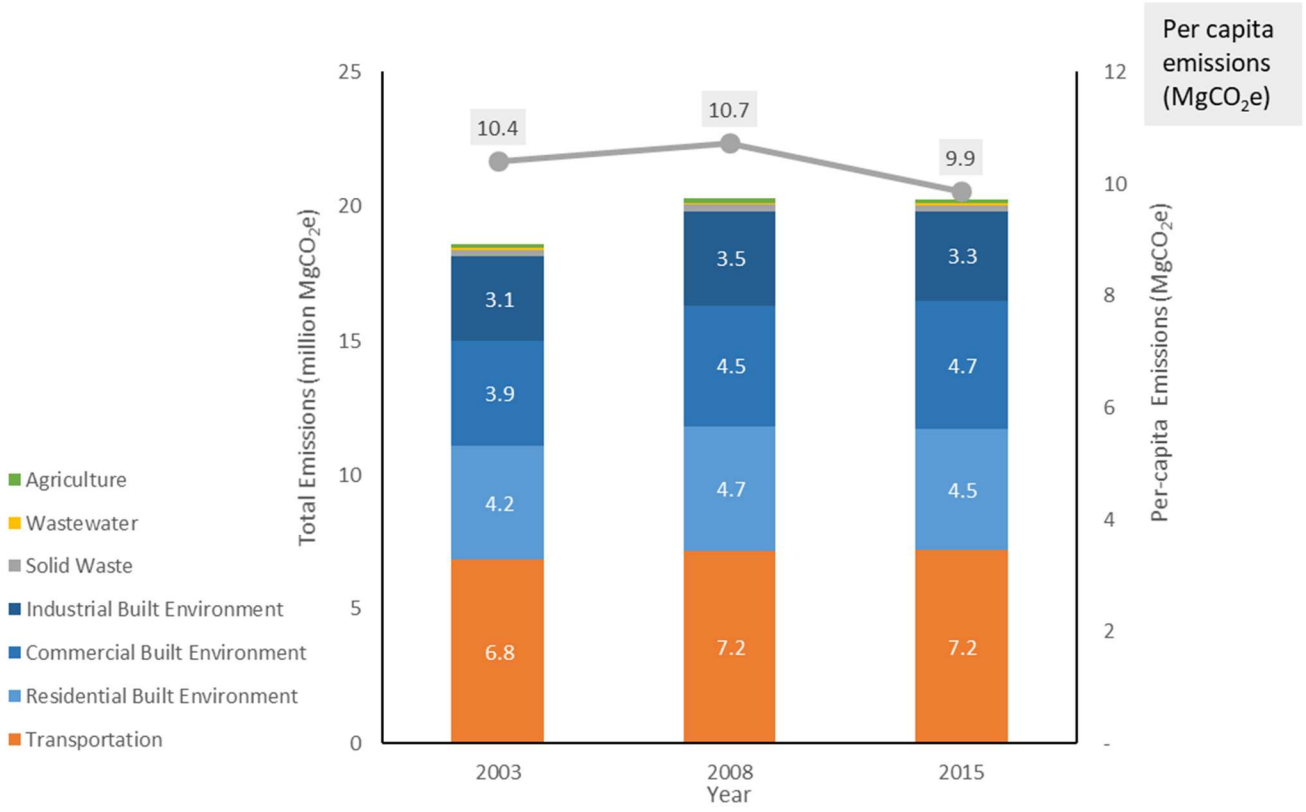


Table 2. King County GHG emissions by sector ($MgCO_2e$).

GHG Emissions by Sector (MgCO2e)	2003	2008	2010	2015
Built Environment	**11,277,100**	**12,654,300**	**9,465,800**	**12,602,600**
Residential	**4,246,500**	**4,677,800**	**4,736,700**	**4,524,400**
Electricity	2,193,300	2,433,600	2,700,100	2,597,100
Natural Gas	1,574,600	1,825,700	1,638,500	1,567,600
Petroleum (Heating)	286,300	216,500	189,300	132,100
Petroleum (Non-road equipment)	192,300	202,000	208,800	227,600
Commercial	**3,919,600**	**4,476,000**	**4,729,100**	**4,737,100**
Electricity	2,335,300	2,682,700	2,992,900	2,955,800
Natural Gas (Heat and Other)	1,034,300	1,174,800	1,096,000	1,147,400
Natural Gas (Equipment)	19,100	16,100	16,800	18,700
Petroleum (Heat and Other)	210,200	245,900	263,900	254,600
Petroleum (Equipment)	159,700	179,200	188,200	212,500
Steam	161,000	177,300	171,300	148,100
Industrial	**3,111,000**	**3,500,500**		**3,341,100**
Electricity	620,600	593,400		611,600
Process emissions	451,500	435,000		351,100
Stationary combustion	1,429,600	1,575,100		1,323,900
Fugitive gas	609,300	897,000		1,054,500
Transportation and Other Mobile Sources	**6,844,300**	**7,152,300**	**6,383,600**	**7,212,500**
On-road vehicles	**6,167,600**	**6,390,600**	**6,383,600**	**6,349,800**
Passenger vehicles	5,017,700	5,251,600	5,217,400	5,142,700
Freight and service vehicles	1,021,400	1,019,700	1,031,400	1,048,600
Transit vehicles	128,500	119,300	134,800	158,500
Freight and passenger rail	**48,800**	**84,600**		**88,100**
Marine vessels	**94,200**	**89,500**		**107,700**
Off-road vehicles and other mobile equipment	**8,100**	**10,200**		**12,300**
Commercial airport	**525,600**	**577,400**		**654,600**
Solid Waste	**260,100**	**245,200**	**237,400**	**225,600**
Generation and disposal of solid waste	260,100	245,200	237,400	225,600
Water and Wastewater	**63,200**	**67,200**	**900**	**73,300**
Potable water process emissions	800	500		900
Wastewater process emissions	62,400	66,700		72,400
Agriculture	**165,100**	**171,700**		**145,500**
Domesticated animal production	69,900	75,500		78,700
Manure decomposition and treatment	95,200	96,200		66,800
Other Emission Sectors (Supplementary)	**109,900**	**65,800**		**58,800**
Soil management	9,700	8,300		9,400
Residential development	100,200	57,500		49,400
Total Emissions (all sectors)	**18,719,700**	**20,356,500**		**20,318,300**
Core & Expanded Production	**18,609,000**	**20,290,200**		**20,258,600**
Core	**13,584,300**	**14,768,700**	**15,065,300**	**14,862,000**
Expanded: Production	**5,024,700**	**5,521,500**		**5,396,600**
Expanded: Supplementary	**109,900**	**65,800**		**58,800**

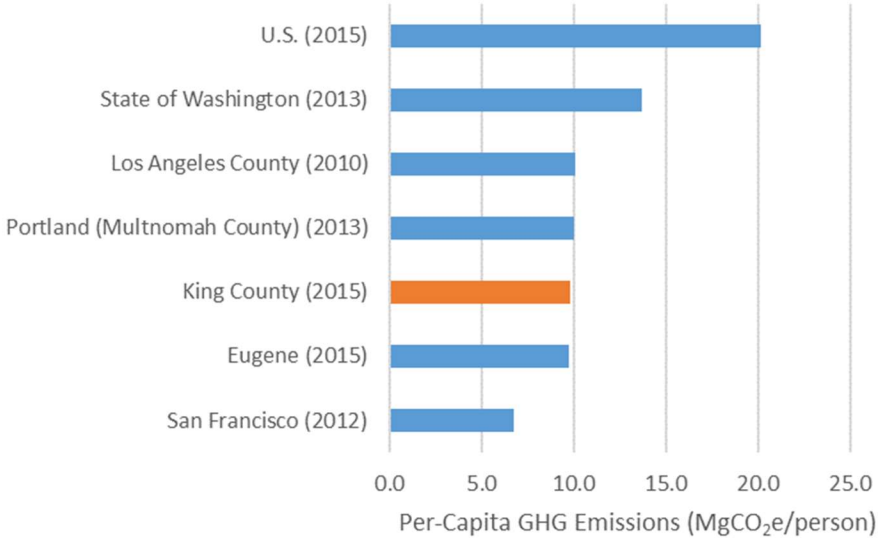
Table 3. King County GHG emissions by sector (percentage of core and expanded production $MgCO_2e$).

GHG Emissions by Sector (% of Total)	2003	2008	2015
Built Environment	**60.6%**	**62.4%**	**62.2%**
Residential	**22.8%**	**23.1%**	**22.3%**
Electricity	11.8%	12.0%	12.8%
Natural Gas	8.5%	9.0%	7.7%
Petroleum (Heating)	1.5%	1.1%	0.7%
Petroleum (Non-road equipment)	1.0%	1.0%	1.1%
Commercial	**21.1%**	**22.1%**	**23.4%**
Electricity	12.5%	13.2%	14.6%
Natural Gas (Heat and Other)	5.6%	5.8%	5.7%
Natural Gas (Equipment)	0.1%	0.1%	0.1%
Petroleum (Heat and Other)	1.1%	1.2%	1.3%
Petroleum (Equipment)	0.9%	0.9%	1.0%
Steam	0.9%	0.9%	0.7%
Industrial	**16.7%**	**17.3%**	**16.5%**
Electricity	3.3%	2.9%	3.0%
Process emissions	2.4%	2.1%	1.7%
Stationary combustion	7.7%	7.8%	6.5%
Fugitive gases	3.3%	4.4%	5.2%
Transportation and Other Mobile Sources	**36.8%**	**35.3%**	**35.6%**
On-road vehicles	**33.1%**	**31.5%**	**31.3%**
Passenger vehicles	27.0%	25.9%	25.4%
Freight and service vehicles	5.5%	5.0%	5.2%
Transit vehicles	0.7%	0.6%	0.8%
Freight and passenger rail	**0.3%**	**0.4%**	**0.4%**
Marine vessels	**0.5%**	**0.4%**	**0.5%**
Off-road vehicles and other mobile equipment	**0.0%**	**0.1%**	**0.1%**
Commercial airport	**2.8%**	**2.8%**	**3.2%**
Solid Waste	**1.4%**	**1.2%**	**1.1%**
Generation and disposal of solid waste	1.4%	1.2%	1.1%
Water and Wastewater	**0.3%**	**0.3%**	**0.4%**
Potable water process emissions	0.0%	0.0%	0.0%
Wastewater process emissions	0.3%	0.3%	0.4%
Agriculture	**0.9%**	**0.8%**	**0.7%**
Domesticated animal production	0.4%	0.4%	0.4%
Manure decomposition and treatment	0.5%	0.5%	0.3%
Other Emission Sectors (Supplementary)	**N/A**	**N/A**	**N/A**
Soil management	N/A	N/A	N/A
Residential development	N/A	N/A	N/A
Total Emissions			
Core & Expanded Production	**100.0%**	**100.0%**	**100.0%**
Core	**73.0%**	**72.8%**	**73.4%**
Expanded: Production	**27.0%**	**27.2%**	**26.6%**
Expanded: Supplementary	**N/A**	**N/A**	**N/A**

Table 4. Per-capita GHG emissions for King County between inventory years.

Per-capita GHG Emissions by Sector ($MgCO_2e$/capita)	2003	2008	2010	2015
Built Environment	**6.3**	**6.7**	**4.9**	**6.1**
Residential	2.4	2.5	2.5	2.2
Commercial	2.2	2.4	2.4	2.3
Industrial	1.7	1.9		1.6
Transportation and Other Mobile Sources	**3.8**	**3.8**	**3.3**	**3.5**
On-road vehicles	3.4	3.4	3.3	3.1
Freight rail	<0.1	<0.1		<0.1
Marine vessels	0.1	<0.1		0.1
Off-road vehicles and other mobile equipment	<0.1	<0.1		<0.1
Commercial airport	0.3	0.3		0.3
Solid Waste	**0.1**	**0.1**	**0.1**	**0.1**
Generation and disposal of solid waste	0.1	0.1	0.1	0.1
Water and Wastewater	**<0.1**	**<0.1**	**<0.1**	**<0.1**
Potable water process emissions	<0.1	<0.1	<0.1	<0.1
Wastewater process emissions	<0.1	<0.1		<0.1
Agriculture	**0.1**	**0.1**		**0.1**
Domesticated animal production	<0.1	<0.1		<0.1
Manure decomposition and treatment	0.1	0.1		<0.1
Supplementary Emission Sectors	**0.1**	**<0.1**		**<0.1**
Soil management	<0.1	<0.1		<0.1
Residential development	0.1	<0.1		<0.1
Total Emissions				
Core & Expanded Production	**10.4**	**10.7**		**9.9**
Core	**7.6**	**7.8**	**7.8**	**7.2**
Expanded: Production	**2.8**	**2.9**		**2.6**
Expanded: Supplementary	**0.1**	**<0.1**		**<0.1**

Figure 6. King County 2015 per-capita GHG emissions compared to other jurisdictions.[2]



RESIDENTIAL AND COMMERCIAL BUILDINGS

Emissions from the residential and commercial built environment resulted in the following key trends and findings:

- In 2015, the built environment accounted for 62% of communitywide emissions. Emissions from commercial and residential buildings accounted for most of those emissions and 46% of all emissions.
- Changes in energy demand and fuel mix in the commercial and residential sectors led to an 6% increase in commercial and 3% decrease in residential energy emissions compared to 2008. Commercial increases can be attributed largely to increases in electricity consumption. Overall, however, natural gas and electricity use has declined in King County since 2008.

King County's electricity and natural gas are delivered through two energy providers: Seattle City Light (SCL) and Puget Sound Energy (PSE). Both providers generate electricity primarily through hydroelectricity, however other sources such as coal and natural gas are also used—especially when hydroelectric capacity is low. Although non-fossil fuel sources constituted a significant portion of both SCL (97%) and PSE (33%) 2015 fuel mix, relative proportions of fuels and resulting emissions factors fluctuate through time (see Figure 7). This change in King County's electricity utilities' fuel mixes have resulted in a fluctuation in the emissions produced per unit of energy delivered over time.

[2] Methodologies may vary among jurisdictions. Only comparable sectors are included in per-capita totals. Comparison is for illustrative purposes only.

King County's electricity is also connected to the regional grid, which has its own emissions profile. To put King County's emissions in context, a sensitivity analysis was run per the recommendations of the U.S. Community Protocol to compare the utility-specific emissions profile with that of the regional grid. In general, the utility-specific emissions profiles out-performed (generated fewer GHG emissions) the regional emission factor. As a policy preference, and consistent with U.S. Community Protocol, King County has requested that we use utility-specific emissions coefficients in this overall inventory to best reflect local conditions and partnerships with Seattle City Light and Puget Sound Energy to phase in renewable electricity sources and phase out fossil fuels.

Figure 7. Sources of residential (left) and commercial (right) GHG emissions in 2015.

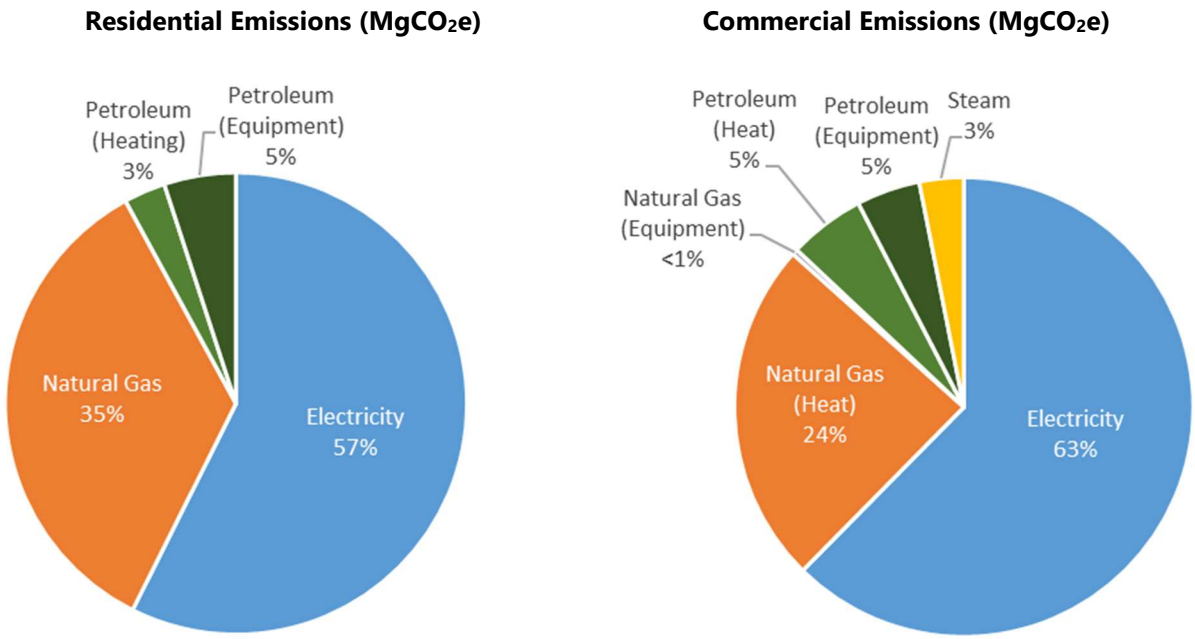
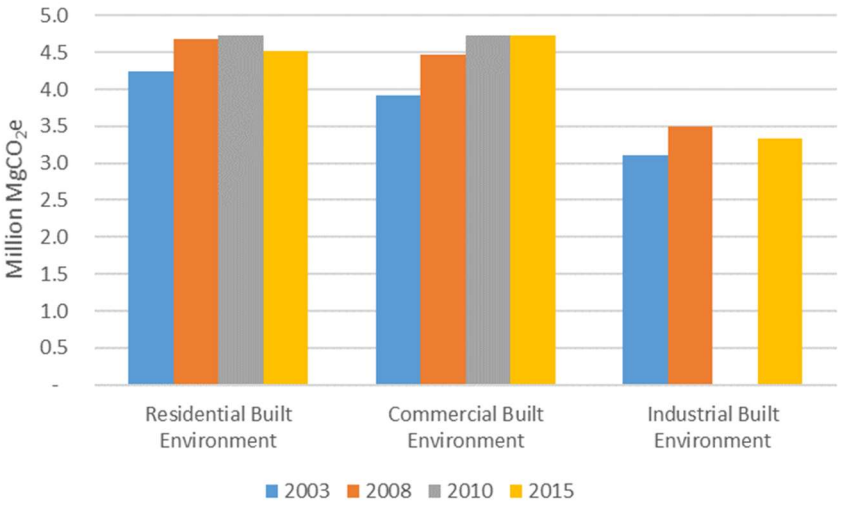


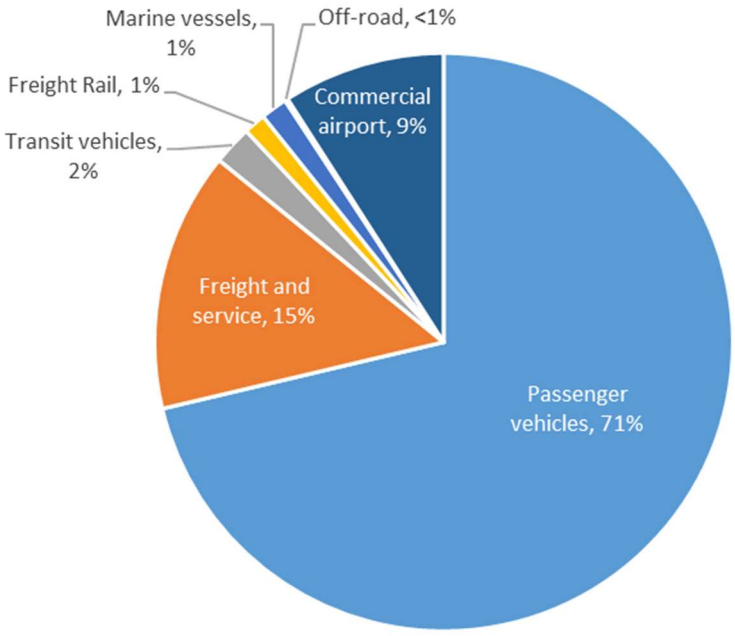
Figure 8. Emission sources from the built environment from 2003 to 2015.



TRANSPORTATION

Transportation accounted for 36% of GHG emissions in 2015, and was the largest source of emissions after the built environment. Total transportation emissions have remained relatively steady since 2008 (Figure 9), and have declined by 7% per capita within that time period. Most transportation emissions in 2015 stemmed from passenger vehicles (71%).

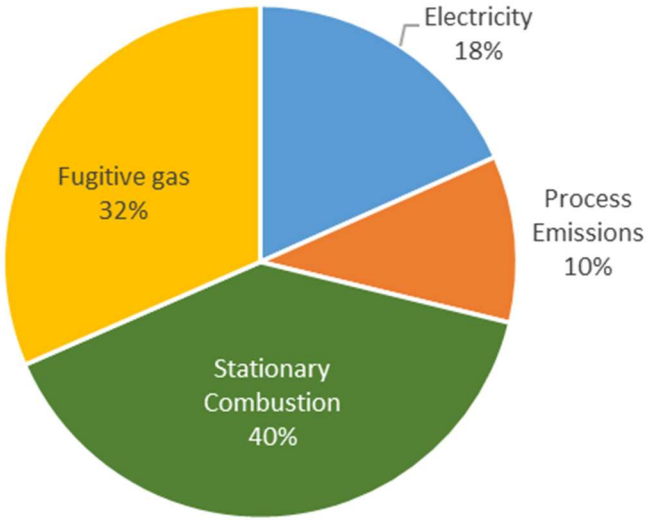
Figure 9. GHG emission sources for transportation in 2015. Commercial airport emissions include airplane takeoff and landing emissions only from SeaTac International Airport and the King County International Airport.



INDUSTRY

Industrial GHG emissions decreased 5% from 2008 to 2015. Emissions from electricity in the industrial sector have increased 3% to about 600,000 $MgCO_2e$ in 2015. Process emissions, a significant portion of overall industrial emissions, have decreased 19% since 2008. Emissions from stationary combustion decreased 16% since 2008, even as electricity demand increased within the industrial sector. Fugitive gas emissions increased 18% between 2008 and 2015.

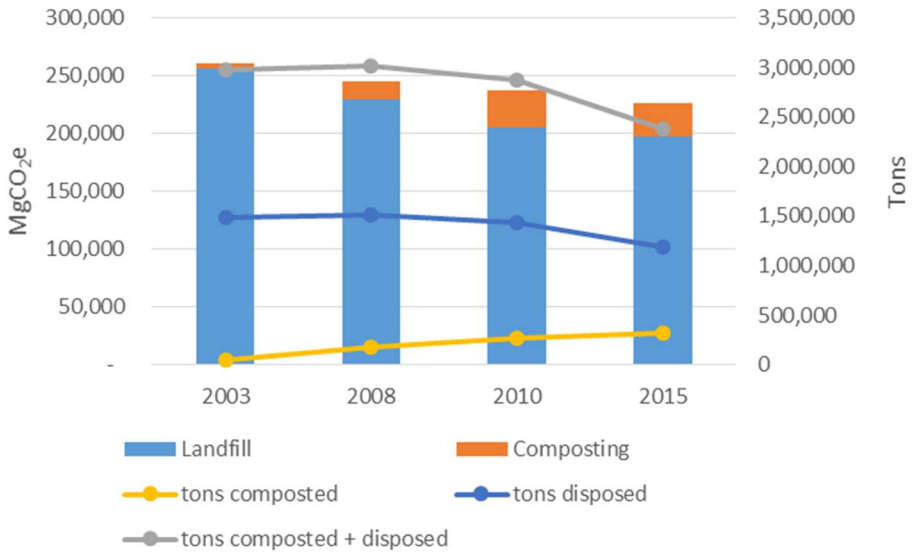
Figure 10. Sources of industrial emissions for King County in 2015 (total = 3.3 million $MgCO_2e$).



SOLID WASTE

Emissions from solid waste disposal have declined in King County since 2003 despite increasing population (Figure 11). Since 2010, emissions have declined 5%, totaling 225,600 $MgCO_2e$ in 2015. Per-capita emissions have decreased 10% over that same timeframe. These estimates do not include the carbon sequestration benefits of solid waste disposal—only the GHG emissions.

Figure 11. GHG emissions from waste disposal.



WASTEWATER

Within a community, emissions from wastewater treatment are dependent on the number of people served and the fuel mix of the energy source. We estimate that wastewater emissions have increased by 9% from 2008 to 2015, and have been relatively stable on a per-capita basis over that period. King County supplies biosolids as fertilizer for several Washington operations, which likely reduces the need for artificial fertilizer. The GHG benefits associated with biosolid fertilizer applications are outside the scope of this inventory.

Supplemental Calculations

The inventory includes calculation of two supplementary emissions sources: 1) soil management and 2) residential development, detailed in the "Agriculture and Land Use Change" section below. We also calculated emissions from two sources for informational purposes only: 1) active landfills and 2) potable water treatment and conveyance. These calculations are purely informational because they overlap with communitywide energy and solid waste emissions, respectively.

AGRICULTURE AND LAND USE CHANGE

Agriculture accounts for only about 1% of GHG emissions in King County, and this relative contribution has remained steady over time. Emissions are primarily derived from enteric digestion of ruminants and manure. Enteric emissions are increasing despite declining per-cattle emissions, indicating an increase in the county's animal population. During the same time, manure emissions declined 31%.

Emissions from soil management increased 13%, but remain very small compared to other sources. In 2015, soil management released 9,400 $MgCO_2e$.

We estimate that emissions from land use change (i.e., residential development) has declined by 14% due to a decline in the number of building permits issued and, consequently, acres of land cleared for new residential construction over that time period.

ACTIVE LANDFILLS

For informational purposes, we also calculated emissions from landfills currently managed by King County. These values are not included in the final inventory tally, as the values overlap with those associated with the generation and disposal of waste by King County businesses and residents.

Data from King County's Solid Waste Division indicate that GHG emissions from Cedar Hills Regional Landfill have decreased by 7% between 2012 and 2016.

Table 5. Landfill GHG estimates for Cedar Hills Regional Landfill

Greenhouse Gas Emissions ($MgCO_2e$)	2012	2013	2014	2015	2016
Cedar Hills Landfill	83,410	65,974	69,056	74,824	77,624

POTABLE WATER

Potable water in King County is sourced from the Cedar River and Tolt watersheds. Like for wastewater, emissions from potable water treatment and conveyance are dependent on the number of people served and the fuel mix of the energy source. Total emissions from potable water used in King County were under 1,000 $MgCO_2e$ in 2015. Overall, potable water is an extremely small source of GHG emissions in King County.

Data Sources

Conducting the inventory involved acquiring the following data, summarized in Table 6 and detailed in the following sections:

- **Activity data** that quantifies levels of activity that generate GHG emissions, such as miles traveled and kWh of electricity consumed.
- **Emission factors** that translate activity levels into emissions (e.g., $MgCO_2e$ per kWh).

Table 6. Key data sources for King County's 2015 geographic-plus inventory.

Sector	Activity	Emission Factors
Transportation (Road)	• Daily vehicle miles traveled (Puget Sound Regional Council)	• EPA MOVES2014a model
Transportation (Transit)	• King County Metro and Sound Transit fuel use	• US EPA (U.S. Environmental Protection Agency, 2015)
Transportation (Air)	• Jet fuel and aviation gas consumed at SeaTac airport and Boeing Field	• US EPA (U.S. Environmental Protection Agency, 2015)
Transportation (Marine)	• Puget Soound Maritime Air Emissions Inventory (Puget Sound Clean Air Agency, 2012) • Washington State Ferries route statements (Washington State Department of Transportation, 2015)	• EPA NONROAD • US EPA (U.S. Environmental Protection Agency, 2015)
Buildings and Industry (Electricity)	• kWh consumption (SCL and PSE)	• Utility fuel mix (Washington State Department of Commerce, 2015) • SCL reported emission factors (The Climate Registry, 2015)
Buildings and Industry (Natural Gas and Oil)	• Gas use (PSE provided by King County) • Oil use (U.S. Energy Information Administration, 2015)	• Carbon content of natural gas and oil (U.S. Environmental Protection Agency, 2015)
Fugitive Gases	• Substitution of ozone-depleting substances • SF_6 emissions from electric utility switchgear insulation	• US EPA (U.S. Environmental Protection Agency, 2015) • IPCC
Solid Waste	• Landfill gas generation • Tons disposed and composted (King County, 2017)	• US EPA WARM v14 model • Customized landfill methane capture rates (Coven, et al., 2014)
Wastewater	• Wastewater treatment rates from King County and Seattle Public Utilities	• National wastewater factors (Local Governments for Sustainability USA, 2013)

Sector	Activity	Emission Factors
Water	• Quantity and use provided by Seattle Public Utilities	• Energy provider emission factor
Agriculture	• Acres of cropland and number of livestock (U.S. Department of Agriculture, 2014)	• Emissions per animal or per acre (U.S. Environmental Protection Agency, 2015)
Land Use Change	• Acres of land cleared for development (King County Assessor's database)	• Average carbon stocks in King County as assessed by the University of Washington

TRANSPORTATION

- **Vehicle miles traveled (VMT)** were derived from Puget Sound Regional Council and accounted for all mileage within the county boundary regardless of trip origin or destination. The PSRC then used emission factors derived originally from the EPA MOVES model and modified those factors to reflect regional vehicle fleet age and fuel composition. The PSRC data reported overall emissions for passenger vehicles (cars, motorcycles, light trucks), medium trucks, and heavy trucks.
- We acquired **fuel consumption** data for Metro (King County's bus transit service) and Sound Transit (a regional transit service that serves King County) from the National Transit Database from the Federal Transit Administration.
- We obtained **jet and aviation fuel data** for Boeing Field from King County and for SeaTac airport from the Port of Seattle.
- **Ferry** fuel data is reported annually by WSDOT for each ferry route. We used the fiscal year that most closely associated with our year of interest.
- The Puget Sound Clean Air Agency published a 2011 report on maritime air emissions, which we used to enumerate 2015 **freight rail and port** emissions. This report is currently being updated to reflect more recent emissions. We recommend that King County update its inventory values when that report is available.
- Emissions from **pleasure boats** and other small-engine recreational vessels were obtained through EPA NONROAD modeling of King County.

BUILDINGS AND ENERGY

- Data on **electricity** and **natural gas** use were provided by the two King County utilities: SCL and PSE.
- **Residential heating fuel** consisted of natural gas, of which the data were provided by PSE, and heating oil, provided by EIA.
- Other residential emissions were calculated from the EPA NONROAD 2008 model output. Emissions include common non-road equipment, often for gardening and landscaping purposes, such as lawnmowers.

- **Commercial heating** is provided through natural gas, and steam from Enwave, a Seattle steam company that heats approximately 200 commercial downtown buildings. Enwave provides emissions data to the PSCAA.
- Additional commercial non-road sources were calculated with the EPA NONROAD 2008 model. These nonroad sources include fuel used for commercial landscaping and non-flight equipment at airports.
- **Industrial process** emissions are recorded by the PSCAA, which provided data on large sources of emissions from industry.
- Data on **fugitive refrigerant** emissions at regional scales is scarce. A nationally reported number by the EPA was used to scale to King County.
- PSE provided data on **natural gas consumption**, and the EIA provided data on **industrial oil**. We obtained emission factors for fuels from the EPA (U.S. Environmental Protection Agency, 2015).
- We calculated an emissions factor for PSE using the fuel mix reported in the annual Fuel Mix Disclosure reporting conducted by the Washington State Department of Commerce. SCL reports an emissions factor through The Climate Registry (TCR), which we used for all years except 2003, which predated TCR. For a 2003 SCL emissions factor, we used the fuel mix report (Washington State Department of Commerce, 2015).

SOLID WASTE

- We used King County waste composition data, along with emissions factors from the EPA WARM v14 model, to calculate emissions from **waste disposal and composting**. Landfill emissions assumed 90% and 75% landfill gas capture rates for King County and Seattle waste, respectively.

WASTEWATER

- Wastewater emission calculations required data from King County **wastewater treatment plants**, provided by facility engineers and publicly available documents.

POTABLE WATER

- **Potable water emissions** required data on water use, publicly available from Seattle Public Utilities, and energy use estimates provided by the U.S. Community Protocol.

AGRICULTURE

- The USDA provides publicly available data on the number of animals by county. The EPA provides national-level **animal enteric and manure** emission factors, and state-level emissions factors for cattle.

LAND USE

- The King County Assessor's office publicly provides land use data for King County, which we used to calculate the emissions associated with **new development** in 2015.

Key Differences between Past and Current Methodologies

This 2015 inventory update was conducted in adherence with the U.S. Community Protocol. See the text box on the following page for more information on this protocol and how it compares to other available protocols.

Several methodological differences between the current inventory and previous inventories led to notable changes in GHG emissions reported (see Table 7). For example, the current inventory includes methane (CH_4) and nitrous oxide (N_2O) emissions from fuel combustion. Previously, only emissions from carbon dioxide were included in combustion emission calculations, with the exceptions of methane emissions from agriculture and waste, and fugitive gases from industry. The current inventory includes updated PSE and SCL emission factors, which led to noticeably different building emissions compared to the previous methodologies. In the past, nonroad vehicle emissions were calculated by multiplying nonroad activity from the EPA NONROAD model with fuel-specific emission factors. The current inventory uses both activity and emission factors from the NONROAD model, which led to a decrease in nonroad emissions for most categories compared to the older methodology.

The sectors for which inventory values changed most drastically due to methodology updates include the following, described in more detail below:

- **Freight and service vehicle** emissions declined compared to the previous methodology due to improved modeling provided by Puget Sound Regional Council.
- **Commercial airport** emissions declined compared to the previous methodology because only landing and takeoff emissions from Seattle-Tacoma International Airport and King County International Airport were included.
- **Industrial stationary combustio**n emissions declined compared to the previous inventory due to updates in the EPA NONROAD model.
- **Residential and commercial electricity** emissions increased compared to the previous inventory due to updated utility emission factors.

The U.S. Community Protocol

The Community Protocol was built to provide easily applicable and accurate community-level estimates of GHG emissions. This protocol provides a consistent framework in which to compare protocols from a geographic boundary across time. The U.S. Community Protocol was designed for community-scale GHG accounting, making it a valuable tool for counties and cities, and an appropriate choice for King County. The Community Protocol is widely used, understood, and respected.

This inventory follows the Community Protocol methodology, and deviates from its stated methods only when more precise, local data is available, per the Community Protocol recommendations. The Local Governments for Sustainability (ICLEI) created the U.S. Community protocol in 2013. The U.S. Community Protocol requires, at a minimum, reporting of the following five activities: 1) Use of electricity by the community 2) Use of fuel in residential and commercial stationary combustion equipment 3) On-road passenger and freight motor vehicle travel 4) Use of energy in potable water and wastewater treatment and distribution 5) Generation of solid waste by the community. Other protocols, such as the Global Protocol for Community-scale GHG Emissions (GPC) are also commonly used. Whereas the GPC focuses primarily on the reporting and categorical requirements of an inventory, the U.S. Community Protocol provides specific methodologies, and often emission factors, to calculate different emissions sources.

This inventory calculates emissions associated with the five activities required of the U.S. Community Protocol, as well as other activities calculated in prior inventory years. The first two activities (community electricity use and stationary fuel combustion) are presented together within the "Residential and Commercial Buildings" and "Industry" sections of this report.

Additionally, the GPC includes consumption-based emissions, and some sinks, whereas the U.S. Community Protocol does not include sinks. Carbon sinks refer to processes that take greenhouse gases out of the atmosphere. By not accounting for sinks, the U.S. Community Protocol can over-represent the net GHG emissions, and allows for some societal goods, such as waste composting, to be perceived negatively. However, other sinks, such as a landfilling, could be perceived positively as a GHG sink, even though increased landfilling of waste is generally not considered a societal good.

Table 7. Brief methodological outline of previous inventories and this report.

Sector	Methodology for previous inventories	Methodology update as part of this report for all past inventory years
Transportation (Road Vehicles)	• VMT from Puget Sound Regional Council (PSRC) data • National emission factors (U.S. Environmental Protection Agency, 2008)	• Emissions calculated by PSRC as a function of VMT, fuel mix, fleet age, and EPA MOVES2014a emission factors • Inclusion of CH_4 and N_2O
Transportation (Transit)	• Transit fuel data used to determine emissions	• No change to transit
Transportation (Air)	• Landing-takeoff (LTO) emissions for King County airport • King County leisure/business travel emissions for SeaTac	• Only included LTO emissions for both King County International Airport and SeaTac • King County resident/business air travel emissions moved to consumption-based inventory
Transportation (Marine)	• Per-route, per-vessel ferry use (no source) • Freight emissions scaled with freight tonnage (Puget Sound Clean Air Agency, 2012)	• Ferry fuel use (Washington State Department of Transportation, 2015) multiplied by diesel emission factors (U.S. Environmental Protection Agency, 2015) • NONROAD model outputs of harbor craft
Transportation (Freight)	• Freight emissions (Puget Sound Clean Air Agency, 2012) scaled to year's tonnage	• No change
Buildings and Industry (Electricity)	• Puget Sound Energy (PSE) and Seattle City Light (SCL) emission factors calculated using fuel mix reports to derive emissions from fuel combustion (Washington State Department of Commerce, 2015)	• Inclusion of CH_4 and N_2O emission factors to fuel mix • TCR-based emission factor for SCL (The Climate Registry, 2015) • TCR-based methodology for PSE emission factor • Accounted for transmission losses
Buildings and Industry (Natural Gas and Oil)	• Quantity of natural gas and oil with emission factor (U.S. Environmental Protection Agency, 2015) • Mobile road emission factors (U.S. Environmental Protection Agency, 2008) applied to NONROAD fuel use data	• Inclusion of CH_4 and N_2O, quantity of natural gas and oil with EPA emission factors (U.S. Environmental Protection Agency, 2015) • NONROAD emission factors applied to NONROAD fuel use data (U.S. Environmental Protection Agency, 2015)

Sector	Methodology for previous inventories	Methodology update as part of this report for all past inventory years
Fugitive gases (ODS substitutes and switchgear insulation SF_6)	• EPA ODS tool • Scaled countywide SF_6 values	• National ODS substitutes value scaled to region by population (U.S. Environmental Protection Agency, 2015) • Utility-specific SF_6 emissions values
Waste	• Waste characterization (King County, 2017) and EPA WARM v8 emission factors	• Waste characterization (King County, 2017) and updated EPA WARM v14 emission factors • Included composting emissions
Wastewater	• Included biogas emissions	• Included biogas emissions, BOD_5 emissions, and septic systems
Potable Water	• Included within community energy (electricity)	• Included within community energy, but also called out as a separate line item
Agriculture	• Enteric and manure emission factors (U.S. Environmental Protection Agency, 2015) and number of animals (U.S. Department of Agriculture, 2014)	• Updated enteric emission factors (U.S. Environmental Protection Agency, 2015)
Land Use Change	• Permit data (King County, 2017) • Carbon storage assumptions	• No change

TRANSPORTATION (ROAD)

On-road passenger vehicle and freight emissions were calculated by the Puget Sound Regional Council (PSRC). PSRC applied its activity-based travel model data to the EPA's Motor Vehicle Emission Simulator (MOVES) model to arrive at emissions estimations by vehicle type.

PSRC's activity-based travel model produces vehicle miles traveled (VMT), facility type, and speed estimates for time periods within a typical workday in King County. VMT outputs were provided by vehicle type for passenger vehicles (further allocated to single occupancy vehicle, HOV2, and HOV3), buses, medium trucks, and heavy trucks. At the time of this inventory, PSRC had developed and calibrated this model for analysis years 2006, 2014, and 2016.

MOVES estimates from cars, trucks, and non-highway mobile sources under user-defined vehicle types, time periods, geographic areas, vehicle operating characteristics, and road types. The model simulates emissions for various vehicle operating processes, such as running, starts, or hoteling. PSRC's use of the model was run using California LEV II standards, which were adopted by the State of Washington beginning with 2009 model year vehicles. PSRC also used County-specific input files provided by the

Washington Department of Ecology that reflect the climate, vehicle mix, and inspection and maintenance requirements specific to each county.

Because the PSRC model was only run for 2006, 2014, and 2016, PSRC linearly interpolated results from modeled years to estimate 2008 and 2015 emissions. To arrive at 2003 emissions estimates, we used regression analysis to estimate 2003 VMT by vehicle type, and then scaled 2008 running and start emissions by the of ratio of 2003 to 2008 VMT.

Transit fuel use for Metro and Sound Transit were multiplied by standard fuel emissions factors from the EPA to derive transit emissions.

TRANSPORTATION (AIR)

Emissions associated with air travel were calculated for jet fuel use and, if available, for ground support equipment. Because ground support equipment is classified as "commercial equipment," its emissions are included in the non-road equipment section of the inventory.

For Boeing Field (King County International Airport) and SeaTac Airport, we obtained data for aviation and jet fuel dispensed on site in 2015. We then applied a standard fraction of that fuel towards King County's share of emissions. This fraction—the proportion of fuel consumed in landing and takeoff (LTO)—is estimated at 10% (Rypdal, 2001). We applied emissions factors from the U.S. EPA Inventory of Greenhouse Gas Emissions and Sinks report (U.S. Environmental Protection Agency, 2017).

For SeaTac airport, greenhouse gas emissions estimates are also available directly from the airport's 2015 air quality criteria pollutant emissions inventory, which uses the Federal Aviation Administration's EDMS model version 5.1.4.1. However, due to limited availability of model outputs prior to 2015, we did not use these data.

Consumption-based Air Travel Emissions

Previous King County geographic-plus inventories accounted for all jet fuel use by King County residents and business travelers through SeaTac airport, regardless of whether the fuel was combusted within King County or outside its air space. To be consistent with the calculation approach used for other transportation modes (e.g., on-road vehicles, marine vessels), we calculated air travel emissions in this section as the total emissions resulting from jet fuel burned during landing and takeoff (LTO) for all planes flying into and out of SeaTac airport (regardless of who was traveling).

The previous methodology—which takes more of a consumption-based approach to quantifying air travel emissions—was also employed and is summarized in the Consumption-based Inventory section of this report. For that calculation, we allocated airshed emissions fractions to individual counties based on respective population and employment statistics. This means that counties with more residents and business travelers are assigned a greater proportion of travel-related emissions at SeaTac airport. We obtained jet fuel supplied at SeaTac for 2015, and then applied emissions factors from the U.S. EPA Inventory of Greenhouse Gas Emissions and Sinks (U.S. Environmental Protection Agency, 2015) to arrive at King County air travel emissions associated with SeaTac airport.

TRANSPORTATION (RAIL)

We used the PSCAA 2011 Maritime Air Emissions report (Puget Sound Clean Air Agency, 2012) and scaled by 2015 tonnage to determine emissions from freight. The Port of Seattle reports rail emissions to the PSCAA, which then breaks down emissions by county in this report. This methodology reflects that used in 2003 and 2008. This estimate may attribute marginally more greenhouse gas emissions to freight because scaling older data fails to account for emission-reducing technological improvements.

BUILDINGS AND INDUSTRY (ELECTRICITY)

Previously, electric utility emissions factors used the fuel mix report for the appropriate year. Washington State Department of Commerce requires an annual fuel-mix report from all public electrical utilities. The new inventory used the 2015 fuel mix report (Washington State Department of Commerce, 2015) to determine PSE's emission factor, but also included CH_4 and N_2O, which had not previously been included. The new inventory retroactively updated previous emission factors to include these gases.

SCL reports to The Climate Registry (TCR) following a rigorous and third-party audited methodology. Per the recommendations of the U.S. Community Protocol, the new inventory uses TCR's reported SCL emissions factor (The Climate Registry, 2015), except for 2003, which predated TCR. We used the fuel mix reported in the Washington Department of Commerce annual 2003 report to determine SCL's 2003 emission factor. We also applied the TCR methodology for calculating utility emissions factors to PSE—the other electricity utility in King County—to arrive at their utility-specific emissions factor.

The US Community Protocol calls for quantification of emissions from electric power transmission and distribution losses. We updated past inventories to account for these losses, which make up about 8% of total electricity generation. Proportional losses were derived from estimated regional grid loss data published by the Emissions and Generation Resource Integrated Database (eGRID).

BUILDINGS AND INDUSTRY (NATURAL GAS AND OIL)

The new inventory uses industrial small equipment emission factors from the EPA NONROAD model rather than mobile emissions factors previously used. PSCAA provided data on combustion and process emissions for large industry. Process emissions occur from the manufacturing of certain goods including steel, cement, and glass, and can be measured by applying an equation to the quantity of material produced.

FUGITIVE EMISSIONS

Previous inventories used a State Inventory tool developed by the EPA to derive regional emissions from ODS substitutes gases. However, this tool is no longer available. Thus, for this inventory update we scaled the national EPA-reported emissions from substitution of ozone-depleting substances (U.S. Environmental Protection Agency, 2015) to a regional scale by population.

We also quantified SF_6 emissions from switchgear insulation used by electric utilities. These values were derived from values reported by the utilities.

WASTE

Previous King County geographic-plus inventories included solid waste emissions through quantification of emissions from landfills within the county. Previous inventories also calculated solid waste emissions from all King County residents and businesses; however, these values were not included in the final geographic plus inventory tally. Because the U.S. Community Protocol prioritizes emissions calculations based on activity boundaries (as opposed to just geographic boundaries), we decided to emphasize emissions associated with all generation and disposal of waste, regardless of where the waste is transferred. This means that the solid waste emissions depicted in King County's inventory include those from Seattle residents and businesses, which are transported to a landfill in Oregon for disposal.

For calculating emissions from generation and disposal of solid waste, we used the same methodology to measure resident and business waste emissions as used in the past, but extracted new emission factors from the EPA WARM v14 model, and reapplied these emission factors to previous years. We translated waste composition data for Seattle and King County (King County, 2017) into the EPA WARM categories and applied travel distance and landfill gas capture data to obtain accurate measures. We also included emissions from composting, which were not incorporated in previous inventories.

Landfill Emissions

For informational purposes, we also calculated emissions from King County's currently managed landfills. These values are not included in the final inventory tally, as the values overlap with those associated with the generation and disposal of waste by King County businesses and residents.

For calculating emissions from closed landfills in Seattle (Interbay, Genesee, Judkins, and South Park landfills), we employed the same methodology as for previous inventories. The City of Seattle is no longer including emissions from the West Seattle closed landfill in the City's greenhouse gas inventory; therefore, we did not include an emissions estimate for that landfill in 2015.

For other closed landfills outside Seattle as well as for the Montlake landfill, we used the California Air Resources Board Landfill Emissions Tool (FOD Model), per the U.S. Community Protocol. Previous inventory values were updated to reflect those model outputs.

King County's Solid Waste Division provided landfill GHG estimates for the Cedar Hills Regional Landfill calculated following the U.S. EPA's Mandatory GHG Reporting Rule protocol, 40 CFR Part 98, Subpart HH (for municipal landfills).

WASTEWATER

King County previously estimated wastewater-related GHG emissions through quantification of emissions associated with the treatment processes and combustion of waste gas. The 2003 and 2008 inventories partially accounted for these emissions by measuring combustion of biogas and nitrous oxide released from wastewater. The new methodology, derived from the U.S. Community Protocol, accounts for GHG emissions from a greater number of processes, and more accurately reflects emissions from wastewater. The U.S. Community Protocol lays out specific methodologies based on how wastewater is treated. Brightwater, a new treatment plant that opened in 2011, was also included for the 2015 inventory. Emissions for previous years were scaled by population and did not include Brightwater. Nearly 85,000 residents in King County use septic systems (King County, 2017), which release methane. We included emissions from septic systems in the 2015 inventory and scaled emissions for previous years based on population.

AGRICULTURE

We updated enteric emission factors for 2015 and previous years to the current reported value for that year (U.S. Environmental Protection Agency, 2015) because changes in emission factors reflect biological differences rather than methodological differences. We also included indirect N_2O emissions from manure management. The equations and the source for animal census data did not change.

LAND USE

The King County Assessor's office supplied data on new residential construction. We used previous equations and carbon storage assumptions to model emissions. New data were used to retroactively update previous years.

POTABLE WATER

Previous inventories did not quantify emissions from potable water as a separate category, but rather as part of the overall community energy use. Potable water emissions are already included elsewhere because emissions are due to electricity use, and thus cannot be summed or these emissions would be double-counted with emissions derived from electrical use. However, by attributing GHG emissions to such processes, this report seeks to provide additional granularity on what processes are responsible for GHG emissions. Groundwater pumping, a source of energy use, was not applicable because King County derives potable water from surface water. Emissions from residential wells are included in the built environment category. The quantity of water conveyed was multiplied by a national kWh/gallon factor within the U.S. Community Protocol to determine energy use. The quantity of surface water (all water for public water for King County) was multiplied by a national kWh/gallon factor within the U.S. Community Protocol to determine energy use. Energy use was then summed and multiplied by the SCL emissions factor to derive emissions related to potable water. Seattle Public Utilities reported water use (Seattle Public Utilities, 2012).

2007 Emissions Inventory

We interpolated each sector of King County's 2003 and 2008 inventories to estimate 2007 emissions. This interpolation allows the County to track progress against its goal to reduce greenhouse gas emissions by 25% by 2020 compared with 2007 levels. For most sectors, we applied a simple linear interpolation of emissions between the two years. One exception is electricity, for which we applied the publicly available 2007 utility-specific emission factors to linearly interpolated estimates of electricity consumption (kWh) to arrive at a total electricity emissions.

Data Source Limitations

Some data from the inherited 2003-2010 workbook were not traceable back to the source dataset. In these cases, we utilized best available datasets:

- **Ferry data:** Previous inventories used fuel use data for each ferry and route by month. We were not able to find a similar dataset for 2015, and thus used fiscal year ferry fuel purchase data from Washington Department of Transportation and retroactively updated past inventories accordingly.
- **Fugitive gases:** The EPA Industrial Process Module for the State Inventory Tool was used previously to quantify emissions from ODS substitutes. We obtained a national EPA value for fugitive gases (U.S. Environmental Protection Agency, 2015) that we scaled by population to King County. We would recommend updating the fugitive gases value if the State Inventory tool becomes available again in the future.
- **2003 VMT:** The PSRC data extended back to 2006. To derive 2003 VMT we modeled available PSRC data and predicted 2003 VMT with the resulting linear equation.

Data Sensitivity to Local Conditions

In the King County 2015 greenhouse gas inventory, some values are associated with locally-derived data, and thus are sensitive to changes in policy within King County and between King County and larger-scale jurisdictions (i.e. Washington state or national). Other values are based on national or regional data, and thus may not accurately reflect King County progress or programmatic influence. In this section, we briefly discuss data sources within the King County greenhouse gas inventory and their associated sensitivity to local influence.

Table 8. Summary of data sensitivity to local conditions for the King County 2015 communitywide inventory

Inventory sector or source	Percent of total 2015 emissions	Values are sensitive to local conditions	Values are sensitive to local conditions, with some exceptions	Values are based on scaled regional/state data	Values are based on scaled national data	Unknown
Electricity	30%		✓			
Natural Gas	13%	✓				
Petroleum heating	2%			✓		
Non-road equipment/vehicles	2%					✓
Steam	1%	✓				
Industrial processes	2%		✓			
Fugitive gas	N/A*				✓	
On-road vehicles (incl. transit)	31%	✓				
Rail	0.4%		✓			
Marine vessels	1%		✓			
Solid waste	1%	✓				
Potable water	0.004%		✓			
Wastewater	0.4%	✓				
Agriculture	1%	✓				
Soil management	N/A*		✓			
Residential development	N/A*	✓				

**Supplementary emissions are not included in the "Core + Production" inventory total.*

Overall, the major emissions categories for King County—electricity, natural gas, and on-road vehicles—are sensitive to local conditions. Once exception is line loss estimations for electricity, which adds 8% to total electricity emissions and is based on regional grid estimates. Collectively, these categories account for 75% of King County's 2015 emissions.

The largest emissions source that may not be sensitive to local conditions is from non-road equipment and vehicles, which makes up 2% of King County's total 2015 emissions.

Sensitivity, by Sector

RESIDENTIAL

Electricity emissions data is derived from emission factors and consumption data for two local providers, Seattle City Light and Puget Sound Energy, and are thus sensitive to local changes in fuel mix and electricity use. Line loss estimations, however, are based on regional values, and thus overall electricity emissions are mixed in their sensitivity to local conditions.

Emissions associated with **natural gas** are calculated with a nationally derived emissions factor and local usage data provided by PSE. These numbers are **sensitive** to local activity.

Petroleum heating emissions are derived from a statewide value of oil-heated homes that is scaled to King County by population and a national emissions factor. These numbers are **not sensitive** to local activity.

Petroleum (non-road) emissions are derived from the EPA NONROAD model, which calculates emissions based on a nationally built model that provides county-specific outputs. It is **unknown** the extent to which these outputs are sensitive to local activity or fuel mix.

COMMERCIAL

Electricity emissions data is derived from emission factors and consumption data for two local providers, Seattle City Light and Puget Sound Energy, and are thus sensitive to local changes in fuel mix and electricity use. Line loss estimations, however, are based on regional values, and thus overall electricity emissions are mixed in their sensitivity to local conditions.

Emissions associated with **natural gas heating** are calculated with a nationally derived emissions factor and local usage data provided by PSE. These numbers are **sensitive** to local activity.

Natural gas equipment emissions are derived from the EPA NONROAD model, which calculates emissions based on a nationally built model that provides county-specific outputs. It is **unknown** the extent to which these outputs are sensitive to local conditions or fuel mix.

Petroleum heating emissions are derived from a statewide value of oil-heated homes that is scaled to King County by population and a national emissions factor. These numbers are **not sensitive** to local activity.

Petroleum equipment emissions are derived from the EPA NONROAD model, which calculates emissions based on a nationally built model that provides county-specific outputs. It is **unknown** the extent to which these outputs are sensitive to local activity or fuel mix.

Steam emissions from Enwave are reported to the Puget Sound Clean Air Agency. Emissions are from local data and thus are **sensitive** to local activity and fuel mix.

INDUSTRIAL

Electricity emissions data is derived from emission factors and consumption data for two local providers, Seattle City Light and Puget Sound Energy, and are thus sensitive to local changes in fuel mix and electricity use. Line loss estimations, however, are based on regional values, and thus overall electricity emissions are mixed in their sensitivity to local conditions.

Process Emissions are associated with local manufacturing of certain products (e.g., cement, glass, steel) and are based on national emission factors and local manufacturing data. Emissions data are **sensitive** to local activity.

Stationary Combustion is based on local use of natural gas, petroleum scaled from statewide data by the proportion of industrial employees, and outputs from the EPA NONROAD model. Although the natural gas consumption is locally-specific, the petroleum and NONROAD data are not, and thus the overall reported value is **not sensitive** to local conditions.

Fugitive gas emissions are mixed. The majority of fugitive emissions—**refrigerant** emissions—are scaled from a national value reported by the EPA, are thus not sensitive to local activity. **Switchgear insulation** SF_6 emissions data, however, are based on utility-specific reporting and are thus sensitive to local conditions. Because SF_6-dervied GHG emissions are relatively small, however, this sector is largely not sensitive to local conditions.

TRANSPORTATION

On-road vehicle activity and fuel mix are county-specific and modeled by the Puget Sound Regional Council using local data. These emissions are **sensitive** to local change.

Truck freight and service vehicle activity and fuel mix are modeled by the Puget Sound Regional Council using local data. These emissions are **sensitive** to local change.

Transit vehicle activity and fuel mix are derived from local fuel data and fuel mix. These emissions are **sensitive** to local change.

Freight Passenger and Rail data was taken from the Puget Sound Clean Air Agency (PSCAA) 2011 Maritime Air Emissions Inventory report and scaled to 2015 by tonnage. This data is based on activity data from local providers, but because of this scaling, is **not sensitive** to changing efficiency.

Marine data were obtained from three sources: EPA NONROAD, Washington State Department of Transportation (WSDOT), and the 2011 Puget Sound Maritime Air Emissions Inventory. It is unknown the extent to which NONROAD modeled **pleasure craft emissions** are sensitive to local conditions. **WSDOT ferry** fuel expenditures were used to determine ferry emissions, and thus are sensitive to local conditions. Emissions from ocean-going vessels were based on local port data, but were then scaled to 2015, and thus are not entirely reflecting of local conditions. Overall, marine emissions are mixed in their sensitivity to local conditions in the target year.

Off-road vehicles and other mobile equipment are modeled in the EPA NONROAD model for King County. Although the model provides county-specific emissions outputs, the extent to which the NONROAD model takes into account local conditions is unknown.

SOLID WASTE

Generation and disposal of solid waste were calculated by applying local waste composition and tonnage values to the EPA WARM v14 model. Emissions factors in the WARM model were modified to reflect local waste transport-related emissions and landfill methane recovery rates. These emissions are thus **sensitive** to local conditions.

Emissions from **operation of solid waste disposal facilities** are based on locally measured or modeled landfill emissions, and are thus **sensitive** to local conditions.

WATER AND WASTEWATER

Potable water emissions are based on US Community Protocol assumptions of energy use per unit water consumed. Electricity emission factors and water use statistics are from local sources. Although energy use per unit water may change with time, this analysis is generally **sensitive** to local activity.

Wastewater process emissions are based on local wastewater treatment facility treatment processes and population served, and are thus **sensitive** to local activity.

AGRICULTURE

Domesticated animal production emissions are based on county animal populations measured by the US Census Bureau and nationally accepted emission factors, and is thus **sensitive** to local activity.

Manure decomposition emissions are based on local animal populations measured by the US Census Bureau and nationally accepted emission factors, and is thus **sensitive** to local activity.

SUPPLEMENTARY EMISSION SECTORS

Soil management emissions are based on EPA emission factors and county-specific cropland statistics from the US Census Bureau. Although the emission factors are not sensitive to local conditions, the basis on county-specific activity data makes these emission values fairly **sensitive** to local conditions.

Residential development emissions were derived from local King County data and are thus **sensitive** to local activity.

Contribution Analysis

Introduction

While the 2015 GHG inventory was compiled, King County was participating in a novel project, *Analyzing Drivers of Change in Greenhouse Gas Emissions Inventories*. Co-led by the City of Bellevue and ICLEI USA – Local Governments for Sustainability, *Analyzing Drivers of Change* is developing new analytic tools to attribute changes in local government GHG inventories to the economic, social and technological forces that caused them. The primary technical goal is to provide a methodology for discovering the reasons for change between two inventories separated in time.

Methodology

Project participants agreed on a mathematical approach to contribution analysis known as a *logarithmic mean Divisa index (LMDI) decomposition*. Despite the imposing name, the methodology is mathematically straightforward and allows for the attribution of each measured change in the GHG inventory to the various factors that caused it (population growth, electricity emissions factors, economic growth, and so forth). ICLEI USA developed a draft tool for applying LMDI to any pair of GHG inventories representing two different years with identical operational and organizational boundaries. The tool features an additional capability to assess correlations between weather and energy consumption and apply these toward further decomposition of changes between the two years.

Cascadia and Hammerschlag collaborated with King County staff to apply ICLEI's draft tool (still in development as of this writing) toward changes between King County's 2008 and 2015 Geographic-Plus GHG inventories, making modifications to the tool as-needed.

ICLEI's draft tool also allows a user to describe project-based GHG reductions and incorporate these into the drivers of change reported as the tool's primary output. During the course of King County's participation in *Analyzing Drivers of Change*, Cascadia and the County collaborated to evaluate GHG emissions associated with seven GHG reduction programs that were active during the 2008-2015 comparison period, and incorporated these into the decomposition analysis.

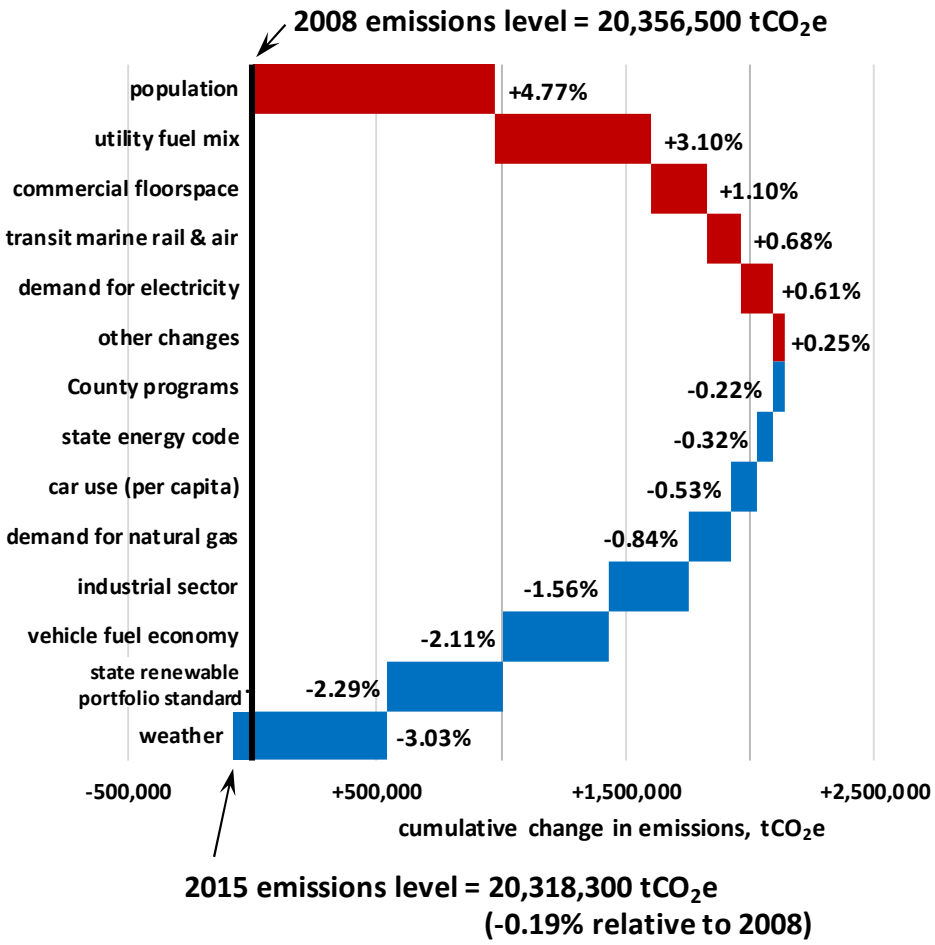
Two of the seven programs were state programs, requiring program evaluation methodologies that ascribed a portion of a statewide reduction to the county. The other five programs were deployed at the county level. The methodologies used to compute the seven program evaluations are described in detail in document KC-047(a) *Program Evaluation Methodologies*, delivered by Cascadia and Hammerschlag to King County on July 7, 2017.

Results

DECOMPOSITION ANALYSIS

In 2008, total emissions (including supplementary sectors) were 20.36 million $MgCO_2e$. In 2015, total emission were 20.32 million $MgCO_2e$, resulting in a 0.19% decrease (38,200 $MgCO_2e$) from the 2008 value. The decomposition analysis (Figure 12) shows that multiple, significant pressures on the GHG inventory worked in opposition to each other to yield this relatively modest net change.

Figure 12: Contributions to change between the 2008 and 2015 total GHG inventories for King County.



The figure shows the influences of 13 forces on the inventory between 2008 and 2015, plus an "other" group of minor contributors.

Population (+972,000 $MgCO_2e$ / +4.77%) includes the impacts of increased housing, increased driving, and increased refrigerant leakage driven by King County's growing population. King County's population increased 8.6% from 1.89 million in 2008 to 2.05 million in 2015.

Utility fuel mix (+631,000 $MgCO_2e$ / +3.10%) is the increase in emissions associated with the greater shares of coal and natural gas in Puget Sound Energy's (PSE's) fuel mix. In 2008, coal and natural gas made up 35.6% and 13.3% of PSE's fuel mix; in 2015, they made up 36.7% and 29.7%, respectively. The increased consumption of fossil fuels during 2015 is associated with a relatively weak hydropower resource that year due to weather.

Commercial floorspace (+224,000 $MgCO_2e$ / +1.10%) increases with growth in business activity in King County and drives increased consumption of energy for heating, cooling, lighting, and other building energy.

Transit, marine, rail, and air (+138,000 $MgCO_2e$ / +0.68%) is the total change in emissions from these forms of transit. They are not subject to the LMDI decomposition, so the bar shows the total change in their emissions, driven in part by population, economic growth, and additional, minor factors.

Demand for electricity (+124,000 $MgCO_2e$ / +0.61%) is the propensity for the county's households and businesses to consume electricity. In the case of businesses this is measured as energy use intensity (EUI), the amount of electricity consumed per square foot of commercial floorspace. In the case of households this is measured per household rather than per square foot. The analysis corrects for the impact of weather changes on energy use, so the results of the decomposition analysis indicate that households and businesses in King County are becoming somewhat more energy intensive over time. Both sectors are increasing; in the case of households this may reflect an increase in average home size, though it is just as likely to reflect changes of equipment or behavior inside the average household.

County programs (-45,300 $MgCO_2e$ / -0.22%) incorporates the GHG reductions associated with various County government initiated programs, specifically transit expansion, growth management, commute trip reduction (CTR), and organics diversion from residential waste.

State energy code (-64,600 $MgCO_2e$ / -0.32%) includes reductions to residential and commercial buildings energy consumption that can be ascribed to strengthening standards within the energy component of the state building codes, as mandated by Washington State law.

Car use (per capita) (-107,000 $MgCO_2e$ / -0.53%) represents the change in driver behavior leading to less gasoline use per person. Specifically, "car use" is defined as vehicle miles traveled for light vehicles.

Demand for natural gas (-171,000 $MgCO_2e$ / -0.84%) is the natural gas correlate of Demand for Electricity. While King County businesses and households showed more propensity to consume electricity in 2015, they showed less propensity to consume natural gas.

Industrial sector (+48,900 $MgCO_2e$ / +0.23%) is self-explanatory.

Vehicle fuel economy (-429,000 $MgCO_2e$ / -2.11%) is the reduction in emissions associated with reduced gasoline consumption in newer vehicles meeting more stringent federal standards.

State renewable portfolio standard (-467,000 $MgCO_2e$ / -2.29%) relates to the reduction in state-average electricity emission factor, that is ascribable to the state's renewable portfolio standard ("I-937"). It is the slowly-changing, policy-driven correlate to the Utility Fuel Mix component above which changes more quickly based on weather and market forces rather than policy.

Weather (-617,000 $MgCO_2e$ / -3.03%) describes the impact that summer and winter temperatures have on emissions from energy consumption. Unusually hot summers increase electricity consumption for air conditioning; while unusually cold winters increase both natural gas and electricity consumption for heating. 2008 and 2015 experienced relatively similar summer weather, but the winter months in 2015 were significantly warmer (less demanding of heat) than in 2008, meaning reduced emissions.

PROGRAM EVALUATIONS

Ten candidate GHG reduction programs were initially identified to complement or support contribution analysis generally (Table 9).

Table 9: Ten programs considered for program evaluation, with final results for seven.

	project active years	inventory category(ies)	GHG red. tCO_2e
Transit Expansion	2008-2015	on-road transport	5,607
Growth Management	2008-2014	on-road transport	24,500
CTR	2008-2015	on-road transport	5,034
Vehicle Stock	*** dropped due to lack of data *****		
State RPS	2008-2012	residential electricity commercial electricity	466,778
other fuel mix changes	*** dropped due to non-separability *****		
Land Clearing Control	2008-2015	"not analyzed"	8,156
State Energy Code	2011-2014	residential electricity residential fuels commercial electricity commercial fuels	64,607
Voluntary Green Building Standards	*** dropped due to lack of data *****		
Organics Diversion	2008-2015	solid waste	2,014

The meanings of the table columns are as follows:

- **Project active years** is the intersection of the period 2008-2015 and the actual years of project activity. For example, if a project started in 2005 and is still in place today, this column will read 2008-2015, not 2005-2017. We are decomposing the difference between 2015 and 2008 emissions, so the project must have been active between January 1, 2009 and December 31, 2015 for it to contribute to that difference. If the project was active during 2008 (all except State Energy Code), then its impact as of calendar year 2008 must be evaluated and subtracted from its impact as of calendar year 2015.
- **Inventory categories** are one or more of the six categories in the ICLEI model (or the "not analyzed" residual) in which the program falls. Two programs straddle categories: State RPS affects residential electricity, commercial electricity, and residential fuels; and State Energy Code affects residential electricity, residential fuels, commercial electricity, and commercial fuels. In the final decomposition analysis, the results of each program evaluation will be subtracted from the listed inventory category's residual.
- **GHG red**. states the GHG reduction computed from program evaluation, per the methodologies described in KC-047(a) *Program Evaluation Methodologies*.

During analysis, three of the ten candidate programs were dropped, leaving seven with final GHG reduction values to incorporate into the ICLEI tool. The two state-level programs showed larger GHG

reductions than the county-level programs so they were included in the final contribution analysis as stand-alone items (Avoided Electric Fuel Mix and State Energy Code). The other five county-level programs were grouped as a single line-item, County Programs.

Discussion

King County's GHG inventory is strongly swayed by population growth, economic growth, weather, utility fuel mix, and federal fuel economy standards, all of which fall outside the direct control of local government.

From 2008 to 2015, King County saw a net 0.19% decrease in emissions as a result of significant positive and negative drivers working against each other. In fact all of the positive forces when combined are over 10% of the inventory in size, counterbalanced with similarly sized negative forces. Population and utility fuel mix alone drove the inventory upwards by 4.77% and 3.10% respectively, while the warmer winter pulled it downward by 3.03% of the 2008 inventory's value.

State Renewable Portfolio Standard, though not quite as large as these others, is a significant downward driver of emissions. State Renewable Portfolio Standard describes the impact of the state RPS on electric generation resources available in Washington State. Without the RPS, the size of the positive Utility Fuel Mix bar would have been even larger: the deployment of the RPS during the 2008-2015 timeframe probably helped offset the impacts of 2015's poor hydropower resource.

King County's population grew by 8.6% from 2008 to 2015, but the induced 4.77% increase in emissions was offset by the strong negative drivers like warm winter weather, the state RPS, and improved vehicle fuel economy.

The combined GHG reduction of the five evaluated county-wide programs was 0.22% of the 2008 inventory value, small compared to some of the drivers that are outside the County's control. The contribution analysis supports the viewpoint that the County's programs are important models for local government initiatives that need to spread widely to increase their reach. This result also would support King County's continued involvement in state and utility policymaking to the extent it has the capacity to do so.

Consumption-Based Inventory

Methodology

The 2015 Consumption-Based Inventory is an update to the calendar year 2008 Consumption-Based Emissions Inventory (CBEI) completed by Stockholm Environment Institute (SEI)[3] and follows the same methodology.

The inventory followed SEI's CBEI Modeler approach and calculations as closely as possible given the available data and documentation. The CBEI Modeler takes as input economic demand by institution type (i.e., household, government, and business) on each of 440 commodity sectors, and calculates GHG emissions by institution type, by life cycle phase (production, transport, wholesale/retail, use, and disposal), and by emission location (within King County, US outside of King County, and Foreign). A detailed description of the methodology is provided by SEI in Appendix D to the 2008 King County GHG inventory report.[3]

We made several important updates to the CBEI Modeler Approach to produce detailed emissions results reflective of the 2015 King County consumption and use. The primary updates are:

1. All end-use consumption (purchasing) volumes in King County and the United States were updated to match known quantities in 2015. The 2015 consumption data were acquired from IMPLAN[4] and are a principal input to the CBEI Modeler. The data characterize commodity demand, import, and exports by institution type for each commodity sector.

   The 2015 IMPLAN data are assigned to 536 different commodity sectors, but the CBEI Modeler is built to accommodate a 440-sector format that was current at the time of the 2008 inventory.[5] IMPLAN provided a "bridge" file that is used specifically to re-assign the new 536-sector data to the old 440-sector format. We used the bridge file to aggregate the 536-sector data into the 440-sector scheme.
   The 2015 IMPLAN demand data is provided in nominal 2015 dollars. To provide comparable results and to conform to the 2008 CBEI model and emission coefficients, the 2015 demand values have been deflated to equivalent 2008 dollars using factors provided by IMPLAN for

[3] "Greenhouse Gas Emissions in King County," Stockholm Environment Institute, February 2012. Available online at: http://your.kingcounty.gov/dnrp/library/dnrp-directors-office/climate/2008-emissions-inventory/ghg-inventory-full.pdf.
[4] Minnesota Implan Group, Inc, 2017
[5] There are some methodological differences in the derivation of demand data by IMPLAN in 2015 versus 2008. These differences have some influence on the comparability of the 2008 and 2015 demand data and emissions results that are discussed in the Results section of this document.

each sector. The overall, demand-weighted deflation is approximately 9.6%. This is consistent with published measures of inflation from 2008 to 2015.[6]

2. End-use emissions data from the 2008 King County Geographic-Plus Emissions Inventory was replaced with emissions data from the 2015 Geographic-Plus Inventory. End-use emissions are those from energy consumed during the both use of the product by the final customer (for example, gasoline for a lawn mower or electricity for appliances) and disposal of the product (landfilling or incineration). The 2015 Geographic-Plus Inventory references local institution data to calculate associated emissions from product use and disposal in King County, including electricity consumption, vehicle use, heat and hot water, garden and recreation equipment, and landfilling. We referenced the results of the 2015 Geographic-Plus Inventory directly as input into the CBEI Modeler.[7]

Conversely, there are two places where the CBEI Modeler has not been updated:

1. The commodity multipliers have not been updated from their 2008 values. These multipliers form the 440x440 input-output matrix and are used to assign consumption in each commodity sector to the various emitting sectors. A single given commodity sector will have 440 associated multipliers which describe how demand on that sector results in different levels of demand on other sectors—i.e., the "upstream" demand. The unchanged multipliers will carry each commodity's *total* 2015 consumption through the analysis, but they will leave the *allocation* of that commodity's consumption to the emitting sectors as it was in 2008. By not updating the multipliers, we assume that a given commodity sector relies on other industries at the same proportion in 2015 as that sector did in 2008.

2. Emissions coefficients have not been updated from their 2008 values. The emissions coefficients translate demand (dollars) on an emitting sector into equivalent GHG emissions. The coefficients are unique to each commodity sector and to geography (King County, US outside of King County, and Foreign). Since the 2015 demand values have been deflated to 2008 dollars, these coefficients remain accurate under the assumption that any given industry has not adopted new, lower-emitting technologies.

[6] U.S. Bureau of Labor Statistics CPI Inflation Calculator: https://data.bls.gov/cgi-bin/cpicalc.pl, accessed 8/16/2017.

[7] The emissions accounting methodology within the geographic inventory has been revised from the original 2008 Inventory. These changes are incorporated into the 2015 CBEI use and disposal calculations but have not been retroactively applied to the 2008 CBEI results, and thus account for some of the difference between the 2008 and 2015 use and disposal emissions estimates. For example, the updated methodology for calculation of emissions from residential lawn and garden equipment results in an estimate approximately eight times that of the previous methodology. Conversely, the calculation methodology for heavy duty truck emissions now results in about 50% of the previous estimate. (These examples were computed by applying the prior and current methodologies to the 2008 dataset.)

Results

Based on 2015 King County commodity use and consumption data, total, consumption-based GHG emissions are 58.2 million metric tons of carbon dioxide equivalent ($MgCO_2e$). This is calculated based on a total commodity demand of $164 billion in 2015 dollars from King County households, government, and businesses in 2015.

Table 10 and Table 11 present the demand (in 2008 dollars) and total estimated emissions by institution type for both King County and the United States, in 2008 and 2015 respectively.

Table 10: Institutional demand and consumption-based emissions in 2008. "$M" means millions of 2008 dollars.

	United States Demand ($M)	King County Demand ($M)	King County Emissions (1000 $MgCO_2e$)
Households	$10,299,248	$93,313	41,743
State and Local Government	$2,147,637	$11,699	3,045
Federal Government	$1,114,883	$4,129	
Business Investment	$2,377,205	$40,458	10,205
Total	**$15,938,973**	**$149,599**	**54,992**

Table 11: Institutional demand and consumption-based Emissions in 2015. "$M" means millions of 2008 dollars.

	United States Demand ($M)	King County Demand ($M)	King County Emissions (1000 $MgCO_2e$)
Households	$11,189,885	$93,285	41,241
State and Local Government	$2,205,050	$18,091	5,508
Federal Government	$1,129,312	$5,337	
Business Investment	$2,983,140	$31,405	11,415
Total	**$17,507,387**	**$148,118**	**58,165**

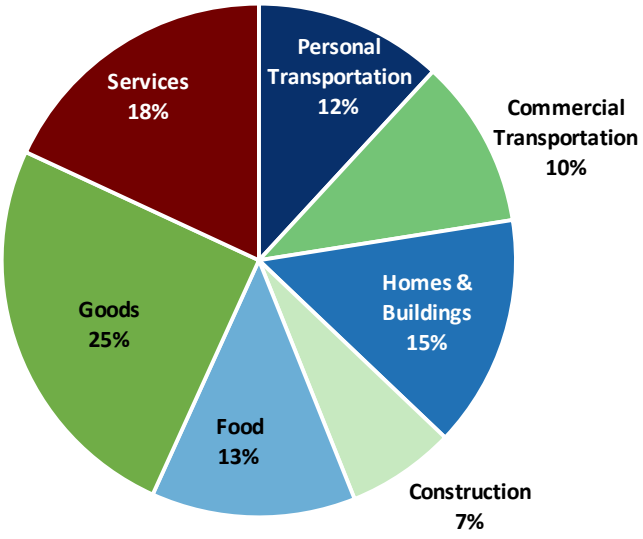
Table 12 through Table 15 compare the total calculated emissions in 2008 and in 2015 for each commodity sector category, institution type, geography, and lifecycle phase.[7] Table 12 shows the emissions for all institution types, geographies, and lifecycle phases combined. Here and in all remaining tables, emissions results are grouped into 16 categories, each of which is an aggregate of several of the 62 CBEI subcategories. Each of the 62 CBEI subcategories is itself an aggregate of several of the 440 IMPLAN sectors.

Table 12: King County total emissions, 2008 and 2015 (1000 $MgCO_2e$).

Category	2008	2015
Appliances, HVAC	4,551	5,059
Appliances, Other	2,571	3,234
Clothing	1,337	934
Concrete, Cement, and Lime	3	11
Construction	4,212	3,955
Electronics	2,427	2,483
Food and Beverages	7,750	7,474
Forest Products	313	317
Fuel, Utilities, and Waste	101	251
Healthcare	3,080	3,646
Home, Yard, and Office	3,488	2,120
Retailer and Wholesaler	2,575	2,280
Services	4,801	6,214
Transportation Services	2,696	3,481
Vehicles and Vehicle Parts	11,322	12,299
Other	3,767	4,405
Total	**54,992**	**58,165**

An overview of the distribution among categories is available in Figure 13. For visual simplicity, the sixteen categories were recombined into the seven meta-categories shown in the figure. Each of the meta-categories is not a simple sum of categories, but rather is computed from a finer breakdown among 62 CBEI subcategories and three institution types. Though less tractable, this approach allows more appropriate assignment of spending to intuitive interpretations of the meta-category names. The mapping between CBEI subcategories and meta-categories is documented in supplementary material provided to King County.

Figure 13. Causes of consumption-based GHG emissions for King County in 2015 (total = 58.2 million $MgCO_2e$).



In general, the share of emissions by category in 2008 and 2015 are similar. For example, in both years, relatively high emissions are found in the categories vehicles and vehicle parts, appliances, food and beverages, and services, which together account for more than half of the total from all categories.

Table 13 shows the emissions broken out by institution type: household, government (combined state, local, and federal), and business. These institution types are as defined by IMPLAN and carried through the CBEI Modeler. In 2015, households were responsible for 63% of total demand and 71% of the total emissions. Households are responsible for the greatest share of the total emissions within nearly all categories, and notably, those with the greatest emissions impact. For example, households account for 80% of total emissions associated with appliances, 95% of food and beverage emissions, and 80% of services emissions. Within the Vehicles & Vehicle Parts category—the largest single category in terms of total emissions—households account for 64% of total category emissions. Business demand includes only business investment in capital and excludes spending on goods or services sold to households, government, or other businesses.[8] Business spending on those sold goods or services is ascribed instead to the institution type of each good or service's end-user.

[8] Business demand does include spending on *unsold* goods (changes in inventory).

Table 13: King County Emissions by institution type, 2008 and 2015 (1000 $MgCO_2e$).

Category	2008			2015		
	Household Demand	Government Demand	Business Investment Demand	Household Demand	Government Demand	Business Investment Demand
Appliances, HVAC	3,925	620	7	4,050	980	29
Appliances, Other	2,085	477	9	2,488	695	51
Clothing	1,330	7	0	923	11	0
Concrete, Cement, and Lime	2	1	0	1	2	8
Construction	600	437	3,175	592	1,054	2,310
Electronics	1,106	251	1,070	1,005	451	1,027
Food and Beverages	7,644	91	15	7,076	384	15
Forest Products	264	49	0	197	106	15
Fuel, Utilities, and Waste	90	8	3	35	35	181
Healthcare	2,995	34	51	3,457	52	137
Home, Yard, and Office	1,770	37	1,681	1,767	126	227
Retailer and Wholesaler	2,351	15	208	2,042	35	203
Services	4,498	229	74	4,977	487	751
Transportation Services	2,403	125	168	2,823	227	432
Vehicles and Vehicle Parts	8,804	371	2,146	7,915	435	3,950
Other	1,878	292	1,597	1,894	429	2,082
Total	**41,743**	**3,045**	**10,205**	**41,241**	**5,508**	**11,415**

Table 14 shows the emissions allocated among the three CBEI geographies: King County, U.S. except King County, and Foreign (outside of U.S.). The results show that about 36% of the total emissions are attributed to King County (primarily appliances and vehicles and vehicle parts), 38% attributed to the U.S. and outside of King County (primarily food and beverages, services, vehicles and vehicle Parts, construction, and health care), and 26% attributed to foreign production. The emissions attributed to each geography include use-phase emissions. As a result, the majority of emissions for categories such as vehicles and appliances, which consume energy in their use, are attributed to King County.

Table 14: King County emissions by geography, 2008 and 2015 (1000 tCO_2e).

	2008			2015		
Category	King County	US, Outside KC	Foreign	King County	US, Outside KC	Foreign
Appliances, HVAC	4,524	13	15	5,013	20	27
Appliances, Other	2,302	78	191	2,978	70	187
Clothing	6	66	1,265	1	36	897
Concrete, Cement, and Lime	0	1	1	4	3	4
Construction	738	2,338	1,135	789	2,051	1,115
Electronics	708	716	1,003	878	574	1,032
Food and Beverages	483	5,457	1,810	418	5,335	1,721
Forest Products	40	177	96	47	194	77
Fuel, Utilities, and Waste	8	62	32	5	215	31
Healthcare	348	2,038	694	506	2,078	1,062
Home, Yard, and Office	653	1,618	1,217	635	717	768
Retailer and Wholesaler	522	1,597	455	503	1,368	409
Services	830	2,882	1,089	1,035	3,743	1,437
Transportation Services	527	1,149	1,019	607	1,785	1,090
Vehicles and Vehicle Parts	7,656	1,752	1,914	6,988	2,466	2,845
Other	368	1,379	2,020	396	1,642	2,367
Total	**19,714**	**21,322**	**13,957**	**20,802**	**22,296**	**15,067**

Table 15 shows the emissions allocated among the five lifecycle phases: production, pre-purchase transport, wholesale and retail, use, and disposal. The production phase accounts for the majority of emissions from most categories; however, as noted below, some of the pre-purchase emissions are due to energy use and disposal by the business providing a product or service.**Error! Bookmark not defined.** The majority of use-phase emissions occur in the following categories: appliances, vehicles and vehicle parts, electronics, and home, yard and office. Significant disposal phase emissions appear mostly in the food and beverages, forest products, home, yard, and office, and services categories.

Table 15: King County emissions by lifecycle phase, 2008 and 2015 (1000 tCO_2e).

	2008					2015				
Category	Producer	Pre-Purchase Transportation	Wholesale+ Retail	Use	Post-Consumer Disposal	Producer	Pre-Purchase Transportation	Wholesale+ Retail	Use	Post-Consumer Disposal
Appliances, HVAC	26	2	0	4,523	0	44	3	0	5,012	0
Appliances, Other	259	11	0	2,300	1	247	9	0	2,977	0
Clothing	1,323	12	0	0	0	926	7	0	0	0
Concrete, Cement, and Lime	3	0	0	0	0	11	0	0	0	0
Construction	3,692	433	24	0	63	3,529	393	24	0	9
Electronics	1,795	70	6	554	1	1,684	56	5	738	1
Food and Beverages	7,052	552	15	0	131	6,795	565	15	0	99
Forest Products	257	18	0	0	37	250	21	0	0	46
Fuel, Utilities, and Waste	97	4	0	0	0	222	29	1	0	0
Healthcare	2,853	212	11	0	4	3,409	221	12	0	4
Home, Yard, and Office	3,067	245	13	60	104	1,446	99	3	552	20
Retailer and Wholesaler	1,586	206	780	0	3	1,395	178	704	0	3
Services	4,494	283	8	0	16	5,771	418	11	0	14
Transportation Services	448	2,244	3	0	0	531	2,948	3	0	0
Vehicles and Vehicle Parts	3,459	294	11	7,555	3	4,977	417	16	6,887	2
Other	3,558	195	9	0	4	4,162	230	10	0	4
Total	**33,969**	**4,783**	**881**	**14,993**	**366**	**35,399**	**5,592**	**805**	**16,166**	**204**

Discussion

CHANGES SINCE 2008

Total Demand (spending): In 2015, after adjusting for inflation, the total demand was approximately 0.99% less than 2008, while total emissions were approximately 5.8% greater. Figure 14 and Figure 15 show the net changes in emissions and demand by category from 2008 to 2015.

Figure 14: King County net emissions change by category, 2008 to 2015.

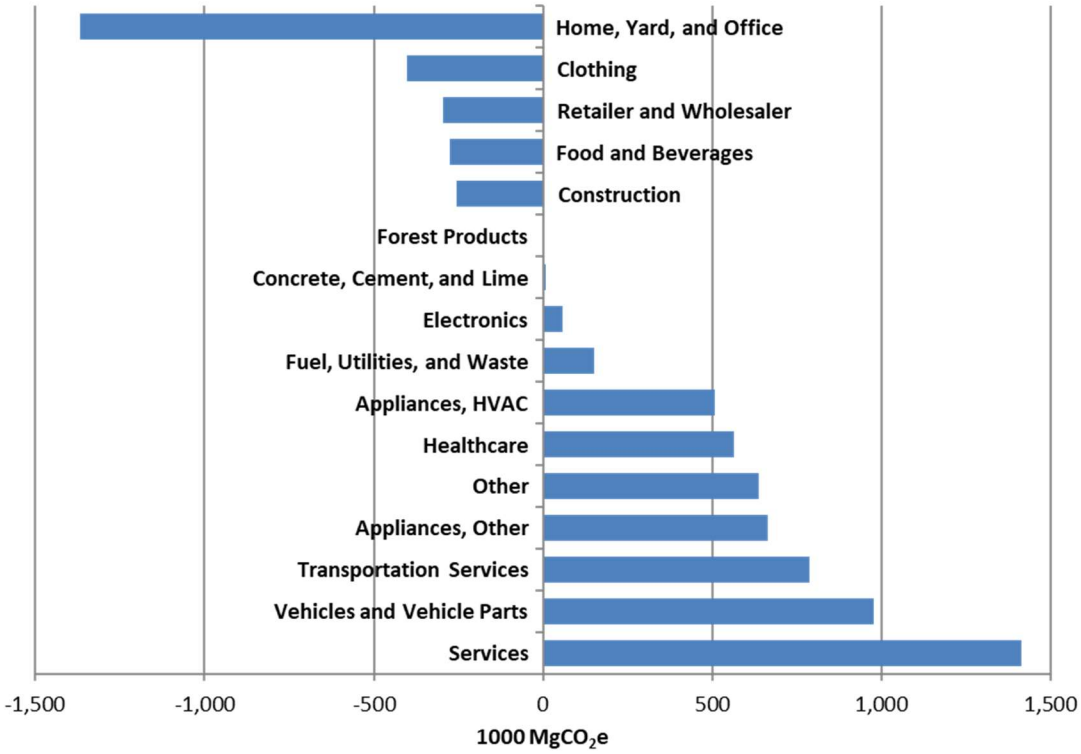
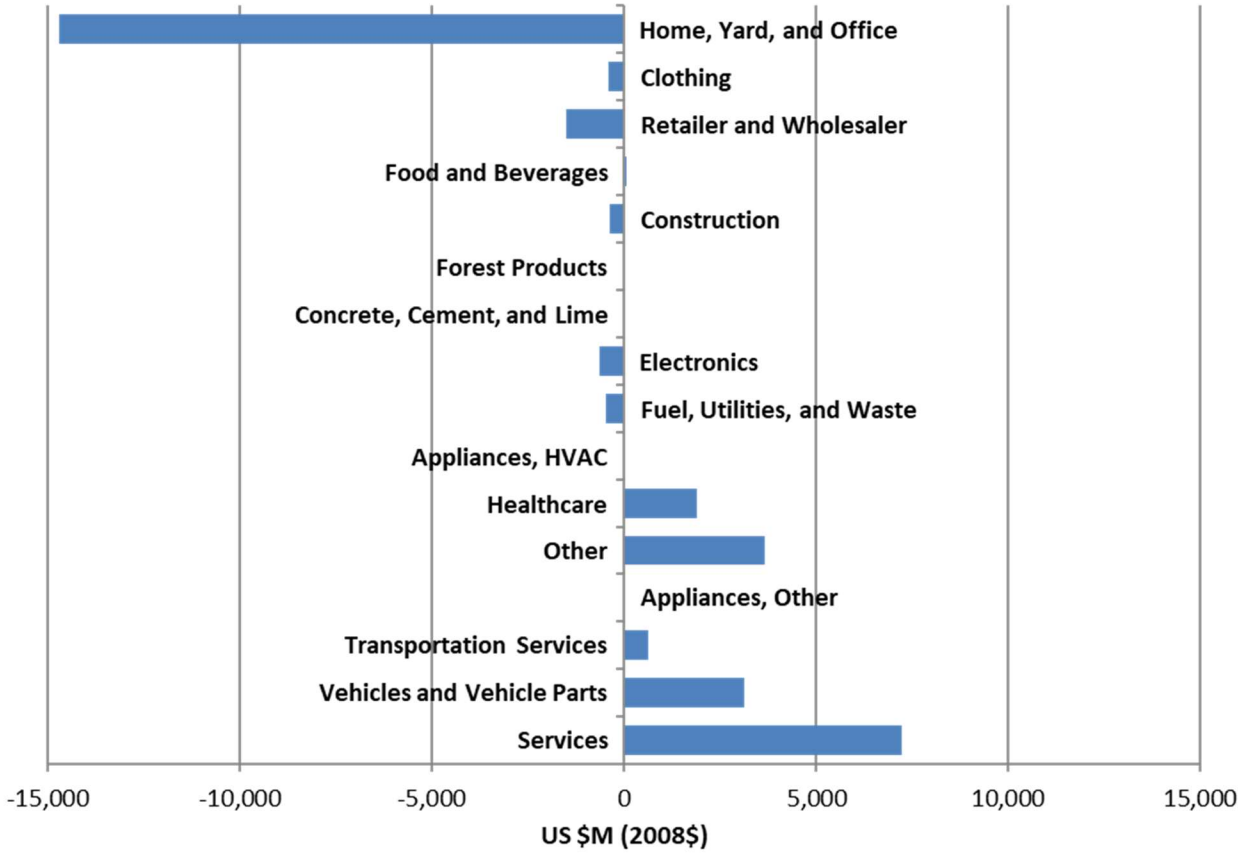


Figure 15: King County net spending change by category, 2008 to 2015.



Comparing Figure 14 and Figure 15 helps illustrate the nuance of the CBEI model as well as the coarse resolution of the 16-category aggregation. For example, electronics, fuel, utilities, and waste, and appliances show a net decrease in spending but a net increase in emissions. In the case of electronics, IMPLAN demand data show decreased spending on computers and custom programming by business and decreased spending on A/V equipment by households, but an increase in spending on wireless communication equipment and computer systems design services in all sectors, as well as an increase in spending on computers by households and government. These changes, and to some degree the updated use phase emissions data, result in a modest reduction in production-phase emissions, a significant increase in use-phase emissions for this category (see Table 15), and higher emissions overall versus 2008.

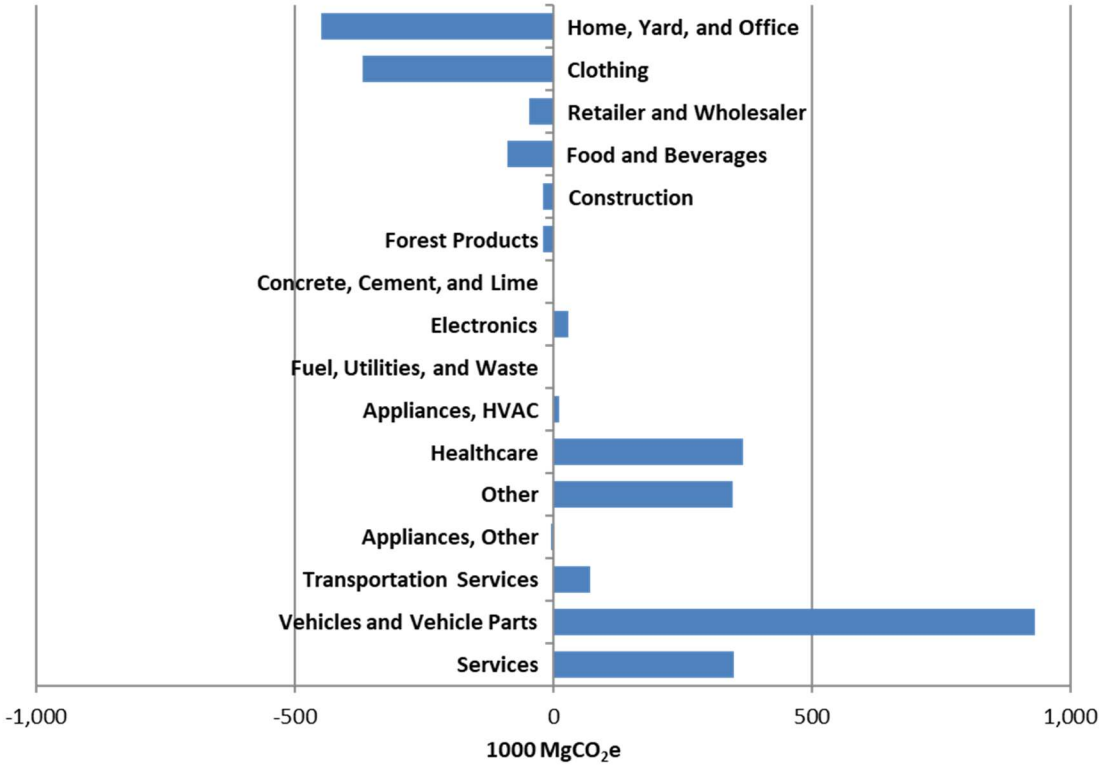
Figure 15 also illustrates an important limitation of 2008 IMPLAN data. The dramatic reduction in spending within the home, yard, and office category is almost entirely driven by a reduction in spending on software by businesses, where the 2008 IMPLAN data showed a business investment of over $15 billion 2008 dollars, or more than 10% of the total King County demand from all institution types. This is an artifact of 2008 IMPLAN demand calculation methodology: demand at the county level is distributed based on that county's production versus the U.S. production. Due primarily to Microsoft's presence, King County "produced" some 22% of the total U.S. software value in 2008, and the IMPLAN methodology thus

assigned 22% of the U.S. software *demand* (approximately $80B) to King County as well. IMPLAN's 2015 dataset was derived with a different, presumably improved methodology. The dramatic difference in this particular sector should be ignored as it does not represent a true change in demand and resulting emissions.

Per-Capita Demand (spending): Between 2008 and 2015, King County's population grew from approximately 1.89 million to 2.05 million, an increase of 8.6%. Over that period, IMPLAN data show gross household demand to stay approximately equal in real dollars. This implies a 7.8% decrease in per-capita spending over the period. This is a significant decline and can be attributed to a combination of true reductions in individual spending (consumer restraint) with reductions in commodity prices on a real dollar basis (economic efficiency). Comparing the 2008 and 2015 household demand data from IMPLAN, many categories show significant reductions in per-capita spending; within the appliances, clothing, electronics, and fuel and utilities categories, per-capita spending drops by 30% to 40%. However, these categories represent less than 5% of total household demand. In the categories with the greatest household demand (i.e., Services, Healthcare, Retailer and Wholesale, and Food and Beverages), per-capita spending changes by +1.2%, +1.9%, -18% and -10% respectively (a 4.8% weighted-average decline among these four categories.

Foreign Imports: While the total imports from outside of King County decreased by about 7.8% from 2008 to 2015, a larger fraction of those imports were supplied from outside the US, resulting in an 8.0% increase in emissions from foreign production. Figure 16shows the changes in emissions induced by changes in demand on foreign production for each category between 2008 and 2015.

Figure 16: King County net emissions change due to foreign production, 2008 to 2015.



The net increase in emissions due to demand on foreign production is largely driven by business demand on the foreign vehicle sector in 2015,[9] and to a lesser degree, the business and household demand on dolls, toys, and games, scientific R&D services, and prescription medication. Though business demand overall fell 20% from 2008 to 2015, demand on foreign production increased 40% during the same period, so that total emissions from business rose 12%.

State, local, and federal government have also increased their demand on foreign production. Though the overall magnitude of emissions from government demand on foreign production is lower than that of businesses demand on foreign production, the rate of increase is much higher. Emissions due to government demand on foreign production increased 94% from 2008 to 2015. The increase was driven

[9] 2008 IMPLAN data show zero demand on the cars and light trucks subcategory from business, whereas 2015 IMPLAN data shows over $2B in consumption by business in this sector. IMPLAN explained this dramatic change as being due to "a change in our data processes and programs" for capital and inventory investment by business. The CBEI modeler calculates the emissions from the reported 2015 demand to be 1.05 million $MgCO_2e$, or approximately 1.8% of the total calculated CBEI emissions.

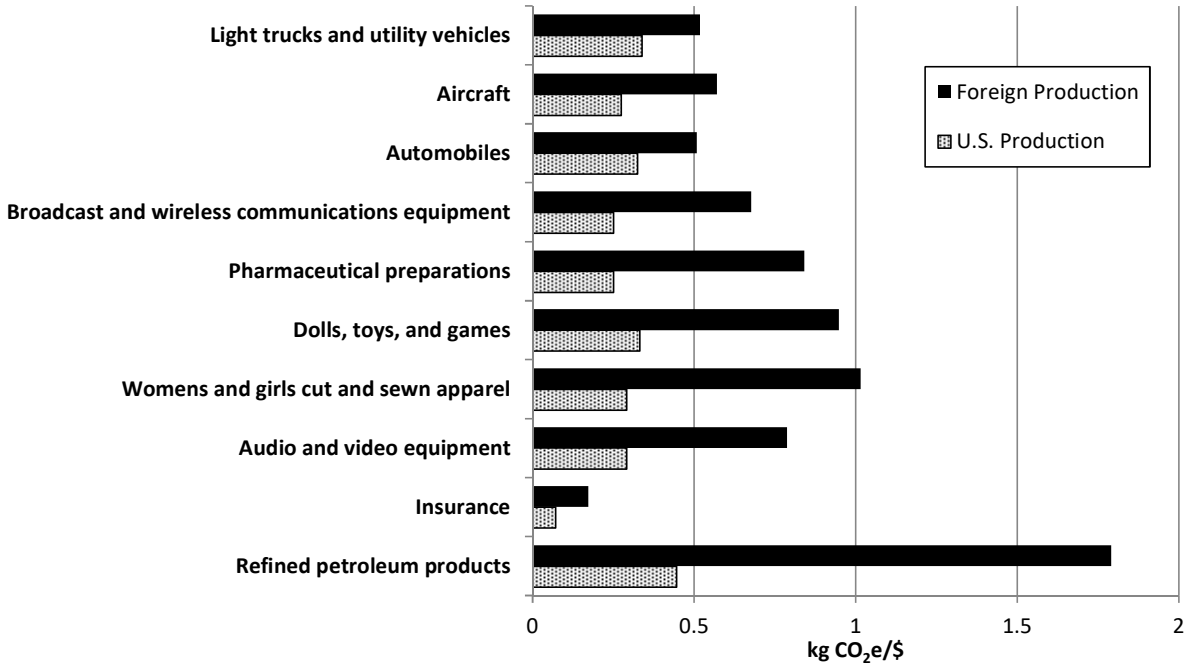
most strongly by spending on wireless communications equipment, gasoline and heating fuels, computer systems design services, scientific R&D services, and non-comparable foreign imports.[10]

Another driver of increased emissions associated with foreign imports are emissions factors (both direct and indirect) associated with foreign production, which are approximately two times higher than those associated with domestic production. Differences in foreign energy generation technologies, environmental regulations, and transport technology (for example less efficient diesel freight transport between foreign sectors) likely lead to the higher foreign production emissions from such industries. Sectors with particularly high foreign production emissions factors include energy-intensive industries such as cement, mineral, and chemical production, as well as energy generation and transport. Additional information can be found in CBEI model documentation (Appendix D of the 2008 Consumption Based Emissions Inventory[3]).

Figure 17 compares the Foreign versus U.S. direct and indirect emissions coefficients for the ten individual sectors with the greatest foreign demand in 2015.

[10] "Non-comparable foreign imports" is defined by IMPLAN as *"goods that are not available anywhere in the nation. They consist of three types of services: (1) services that are produced and consumed abroad, such as airport expenditures by U.S. airlines in foreign countries; (2) service imports that are unique, such as payments for the rights to patents, copyrights, or industrial processes; and (3) service imports that cannot be identified by type, such as payments by U.S. companies to their foreign affiliates for an undefined 'basket' of services"*.

Figure 17: Foreign versus U.S. direct and indirect emissions intensity coefficients ($kgCO_2e/\$$)



Household Consumption: Households still accounted for the majority of emissions; in 2015, approximately 71% of the total emissions were from households, compared to 76% in 2008.. There was a negligible change in total household demand (in real $) from 2008 to 2015 of approximately -0.03%. Again, household demand represents such a large share of the emissions in part due to business spending on production, which is not attributed to businesses but instead to the end-user of each good or service.

Government Consumption: Government institutions (local, state, and federal) accounted for a relatively small share of total emissions, though this share has increased from 5.5% in 2008 to 9.5% in 2015 (overall government emissions increased by 81%). The increase in emissions is associated with a 48% increase in demand from government institutions, including a significant increase on foreign demand as noted above. Notable sector categories showing increased government demand, and associated emissions, include construction, appliances, food and beverages, electronics, and services. These categories generally have relatively moderate emissions coefficients; however, within the food and beverage category, red meat, dairy, and poultry all have relatively high emissions coefficients. Government demand on these three sectors combined increased nearly 400% between 2008 and 2015. The impact of increased food and beverage consumption is significant; it is unknown whether this is simply more food consumed by government employees and their guests or whether this signals some more substantive difference such as a change in the accounting of food subsidies. As noted above, the per-capita *household* consumption within the food and beverage category did decline from 2008 to 2015 by 13%.

LIMITATIONS OF THE PARTIAL UPDATE

Being a partial update, this inventory has some inherent limitations which should be acknowledged.

As described in the Methodology section, two major components of the model are identical in the 2008 inventory and in this partial update: (1) The 440x440 input-output matrix, and (2) the emissions intensity coefficients ($kgCO_2e/\$$). The impacts of retaining the 2008 values in these two CBEI components, both on the gross and disaggregated emissions, is unknown; however, there is certainly some impact as these components are principal to the emissions calculations. As mentioned previously, our analysis effectively assumes that (1) in 2015, a given commodity sector relied on other industries at the same proportion as that sector did in 2008, and (2) in 2015, any given industry produced the same emissions for a given level of production as it did in 2008 (i.e., no new, lower-emission technologies had been adopted).

There is some limitation to the comparability of the 2008 and 2015 data due to differences in the methodology employed by IMPLAN in their calculation of the sector demands.[9] The magnitude of this impact is unknown, but this does add a significant caveat to the discussion around changes from 2008 to 2015. This issue is also addressed below in the Process Improvement section.

Given these limitations, it is recommended that the results of this partial update be interpreted with an appropriate understanding of uncertainties, and that a full update eventually be conducted to address these limitations.

PROCESS IMPROVEMENT

We updated CBEI results with updated demand data as input, using the CBEI Modeler platform developed by SEI for the 2008 inventory. This required first a detailed review of the data flows and built-in algorithms, followed by some manipulation of the model and its inputs in order to utilize the robust analytical features without updating the entire model.

Through this process, some challenges were identified that could be considered for improvement during the next "full" update of the King County CBEI. The lessons learned might also have value for consumption-based inventories in other regions, or for estimating different byproducts or impacts of consumption. Four primary improvements stand out:

Inter-Year Comparability: The 2008 and 2015 demand data sets for King County were computed by IMPLAN using different methodologies in some places, which have produced some incomparable demand data and anomalous emissions results.[9] The 2008 IMPLAN demand data for King County distributes *demand* based on the proportion of U.S. *production* that comes from the County, which is not necessarily representative of the real demand and could thus produce inaccurate emission results. To provide better comparability between 2008 and 2015, and to more accurately represent the King County demand in 2008, the IMPLAN "time series" data product could potentially be utilized, which applies an updated and consistent methodology for all years. This would require re-modeling 2008 data and would yield different results than were produced in the previous 2008 CBEI model. There is a risk of other challenges arising when incorporating the different data product in the CBEI Modeler.

Model Simplification: The CBEI Modeler invokes complex data flows between Microsoft Access databases and Microsoft Excel worksheets, including many macros and linked references that make it quite difficult to troubleshoot or confirm the data flow through the model. Simplifying the model to run on a single platform—whether Excel, SQL, Matlab, or other platform, could allow for better visibility and comprehension of the model as a whole. Where possible, stages and processes could be combined and presented sequentially through the user interface.

Model Accessibility and Documentation: The CBEI Modeler is challenging to comprehend in detail by a third party. The accompanying documentation does provide useful explanation of the algorithms within the model, but there are many elements within the Modeler—macros, linked data values, static data values, scalars and adjustments, etc.—that are only understood through a deeper dive, and even that level of detail may not lead to full comprehension. In addition to the simplification suggested above, revision or replacement of the CBEI Modeler should also focus on accessibility and visibility, notation, and clear documentation of all data sources and processing stages.

Model Adaptability: The complexity of the existing CBEI Modeler makes operation beyond the built-in 2008 King County data set fairly challenging. There are features to customize demand; however, this is meant for single-sector manual entry. Updating the results for the 2015 demand data required substantial manipulation of the model and introduced greater risk of error in the results. A revision of the CBEI process should incorporate flexibility and foresight in its construction and interface such that users could more easily adapt the model for another inventory, taking into account, for example, different demand data, data/model year, regions, or even economic byproducts or environmental impacts.

Conclusion

The updated geographic-plus and consumption-based inventories, as well as the contribution analysis, provide a snapshot of 2015 GHG emissions in King County and how emissions have changed over time.

Greenhouse gas emissions within King County decreased 0.16% from 20.29 million $MgCO_2e$ in 2008 to 20.26 million $MgCO_2e$ in 2015. Over the same period, per-capita emissions have declined 7%. This report also analyzed what factors lead to these observed changes. Among the largest drivers of change were population growth (4.77% increase in emissions), changes to the utility fuel mix (contributing to a 3.10 percentage point increase over 2008 emissions), the state renewable portfolio standard (2.29 percentage point decrease relative to 2008 emissions), and warmer weather in 2015 (3.03% decrease in emissions). These factors have a substantive impact on the inventory, although the County has limited control of several of these drivers of change.

The consumption-based inventory also suggests a few notable trends: a negligible change in total demand (spending) despite the 8.6% increase in population; a relative decrease in household demand when compared to business and government; and an increase in foreign imports. On a consumption-basis, total emissions increased by approximately 6% from 2008 to 2015.

King County's Strategic Climate Action Plan set a target to achieve a 25% reduction in greenhouse gas emissions by 2020 compared with 2007 levels. More work will be needed by King County and partners to meet this ambitious goal.

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