Addendum to Metro Vancouver Regional Consumption-Based Emissions Inventory

CHRM Consulting

Sustainability managers

BCIT CENTRE FOR ECOCITIES

Table of Contents

List of Tables

List of Figures

Introduction and Background

This report is a companion document and update to the 2015 Metro Vancouver Consumption-based Emissions Inventory[1] prepared by CHRM Consulting and JM Sustainability Managers in 2021.

This document provides:

- An updated 2015 Consumption-based Emission Inventory (CBEI)
- A 2015 ecological footprint assessment
- A summary of methodological refinements and additional data that has been incorporated into the inventory, and
- An updated methodology for the 2015 CBEI.

The updated inventory results provided in this addendum can be used as a revised 2015 baseline for future CBEIs.

[1] http://www.metrovancouver.org/services/air-quality/AirQualityPublications/MetroVancouverConsumption-BasedEmissionsInventory.pdf

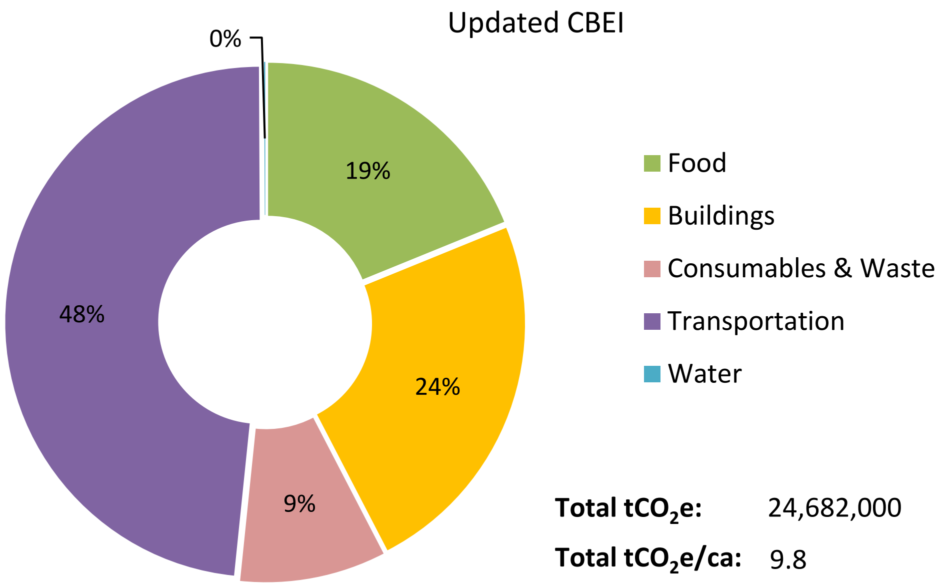
Summary of Updates

The methodological refinements and additional data that are incorporated into the updated CBEI and the new ecological footprint assessment are summarized below by category.

	Original CBEI	**Updated CBEI**
Food Transport	Only included impacts of transport of food imported into Canada	Now also includes impacts of domestic transport of food
Embodied Emissions of Fuels	Global averages used to estimate embodied emissions of fuels (extraction, processing, transport, etc.)	Local factors for embodied emissions of fuels for British Columbia and Alberta are now used (the majority of BC fuels are derived from BC and Alberta sources)
Embodied Emissions of Vehicle Materials	Included embodied emissions of vehicle materials as a percentage of operating emissions, using factors derived from vehicle lifecycle assessment analysis	Vehicle material embodied emissions are now calculated based on vehicle counts and LCA factors by vehicle type
Embodied Emissions of Materials for Ferries, Rail & Air Travel	Not included	Embodied emissions of materials for BC Ferries vessels, West Coast Express trains, and commonly used commercial aircraft are now included
BC Ferries Emissions Allocation	BC Ferries emissions were allocated by jurisdiction as a percentage of BC population	Additional research and analysis were conducted to better determine the appropriate allocation of BC Ferries emissions to BC jurisdictions
Ecological Footprint	Not included	Built area data is now included in the analysis allowing for the calculation of an ecological footprint in addition to a CBEI

Updated 2015 CBEI

The net impact of the updates resulted in an increase of 6% in the CBEI (Figure 1, Table 1). There is only a minor shift in the relative impact of each category, with buildings having the most significant change increasing from 22% to 24% of the total emissions (Figure 1, yellow).



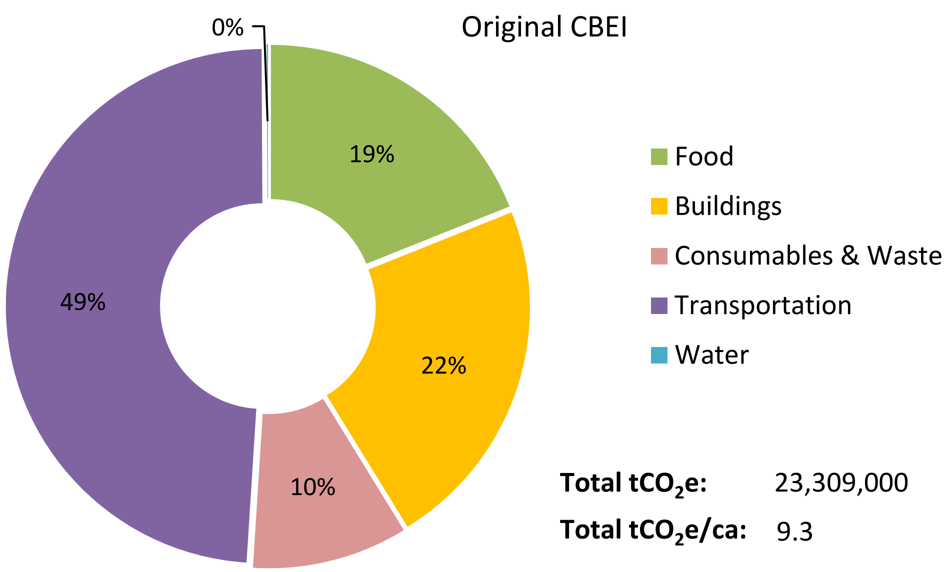


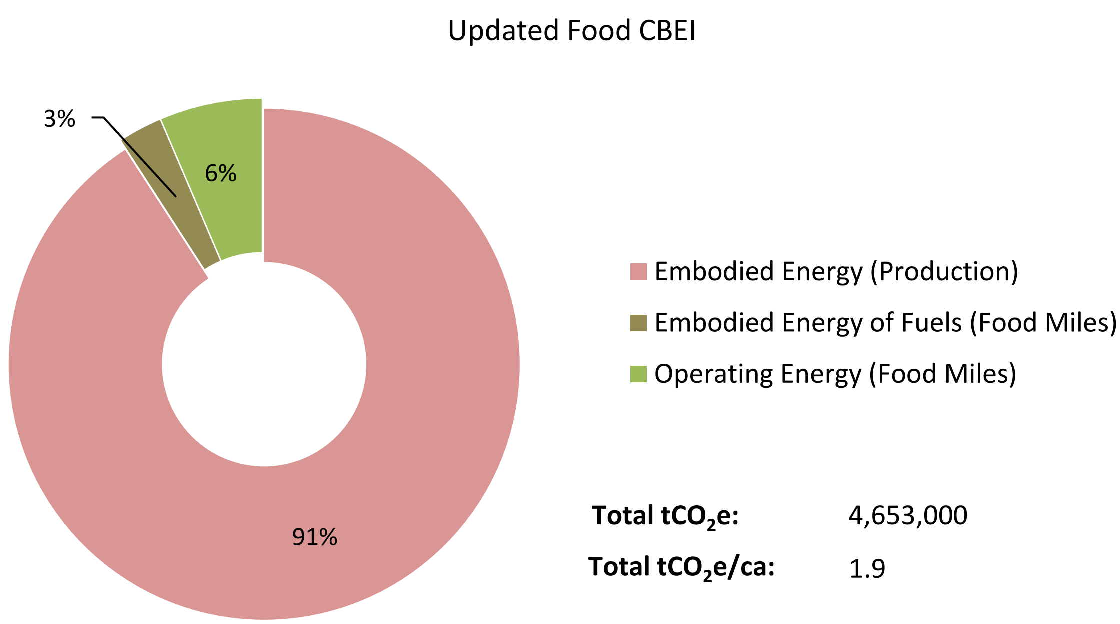
Figure 1: Updated & Original CBEI for the Metro Vancouver Region, 2015

Table 1: Updated & Original CBEI for the Metro Vancouver Region, 2015

	Updated CBEI (tCO_2e)	Original CBEI (tCO_2e)	Change
Food	4,653,471	4,415,053	238,418
Buildings	5,807,247	5,194,094	613,153
Consumables and Waste	2,283,818	2,281,042	2,776
Transportation	11,919,006	11,399,935	519,071
Water	18,872	18,529	343
Total	**24,682,000**	**23,309,000**	**1,373,000**

CBEI of Food

The addition of domestic transport of food results in roughly double the transport emissions previously estimated using only the transport of food imported into Canada (Figure 2, Table 2). The updated embodied emission of fuels factors for liquid fuels are roughly double the global average values used previously, resulting in a further increase of emissions associated with food transport. However, the relative impact of food transport remains low with over 90% of emissions still associated with food production.



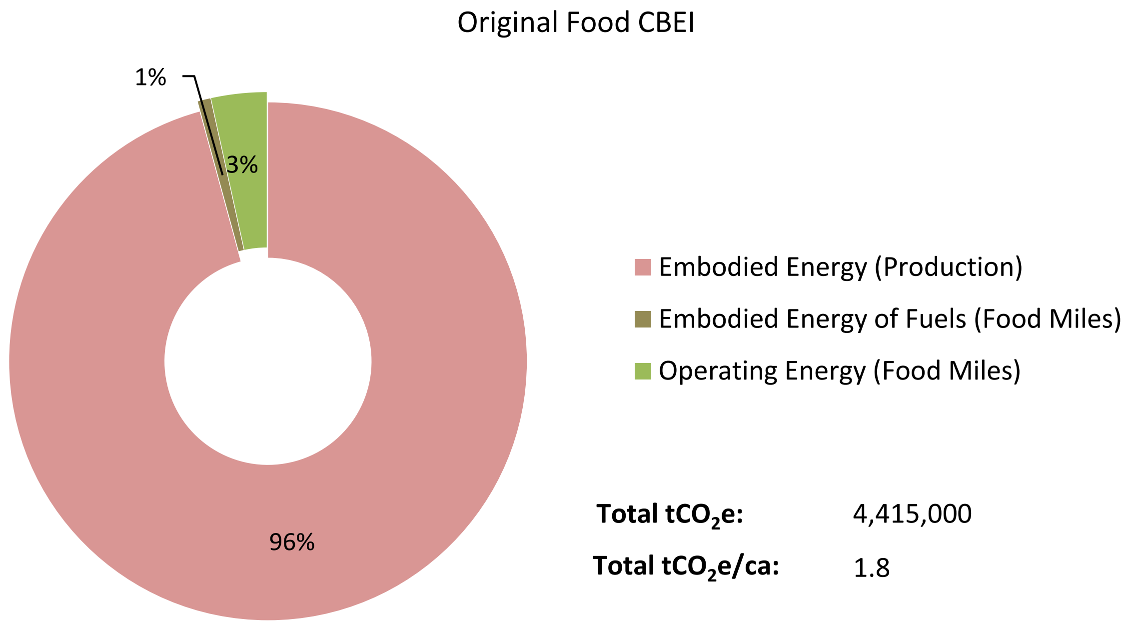


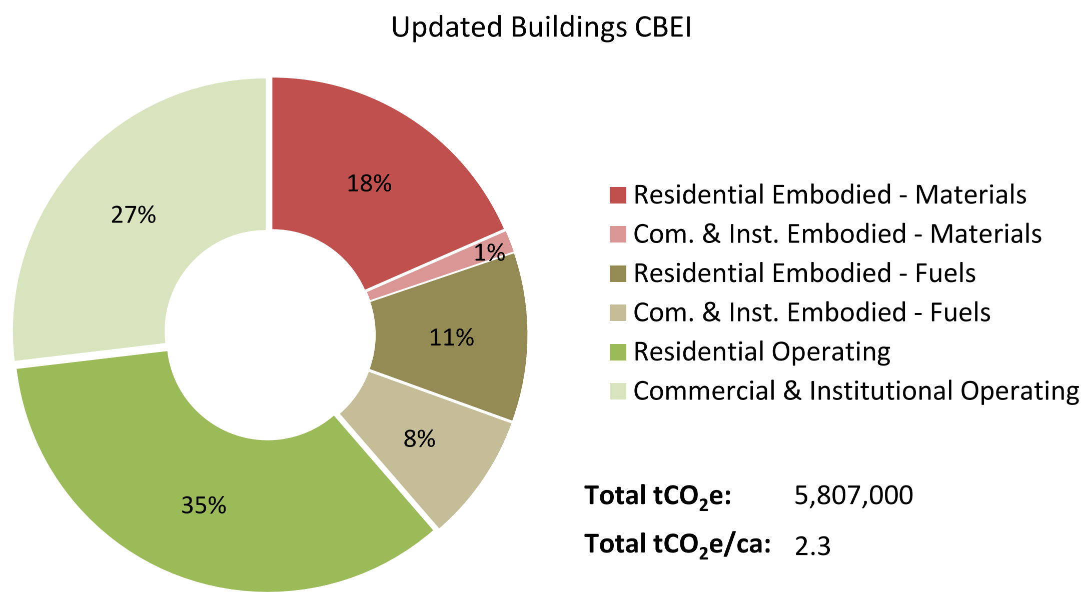
Figure 2: Updated & Original CBEI of Food for the Metro Vancouver Region, 2015

Table 2: Updated & Original CBEI of Food for the Metro Vancouver Region, 2015

	Updated CBEI (tCO_2e)	*Original CBEI (tCO_2e)*	*Change*
Embodied Energy (Production)	4,227,257	4,227,257	0
Embodied Energy of Fuels (Food Miles)	127,231	35,336	91,895
Operating Energy (Food Miles)	298,983	152,461	146,522
Total	**4,653,000**	**4,415,000**	**238,000**

CBEI of Buildings

The updated factors for embodied emissions of fuels are roughly double the global average values used previously, resulting in an increase of 613,000 tCO_2e from fuel use in buildings (Figure 3, Table 3).



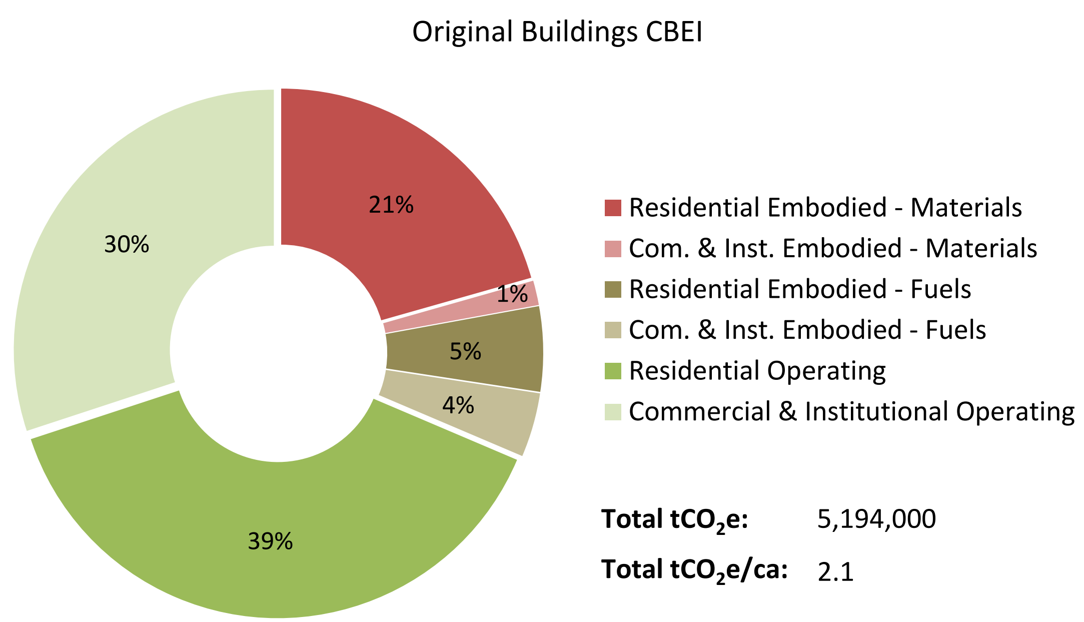


Figure 3: Updated & Original CBEI of Buildings for the Metro Vancouver Region, 2015

Table 3: Updated & Original CBEI of Buildings for the Metro Vancouver Region, 2015

	Updated CBEI (tCO_2e)	*Original CBEI (tCO_2e)*	*Change*
Residential Embodied - Materials	1,069,996	1,069,996	0
Com. & Inst. Embodied - Materials	79,309	79,309	0
Residential Embodied - Fuels	623,752	274,146	349,606
Com. & Inst. Embodied - Fuels	471,102	207,554	263,548
Residential Operating	2,002,308	2,002,308	0
Commercial & Institutional Operating	1,560,781	1,560,781	0
Total	**5,807,000**	**5,194,000**	**613,000**

CBEI of Consumables and Waste

The updates had a negligible impact on overall emissions for consumables and waste (Table 4).

Table 4: Updated & Original CBEI of Consumables and Waste for the Metro Vancouver Region, 2015

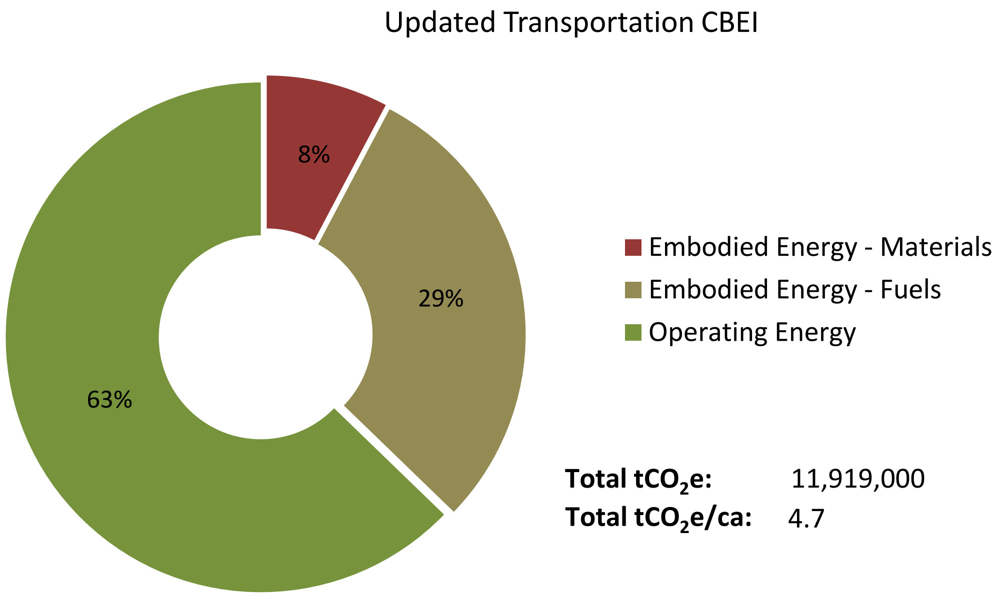
	Updated CBEI (tCO2e)	*Original CBEI (tCO2e)*	*Change*
Materials Disposed	417,077	417,077	0
Embodied Energy of Materials Disposed	1,564,706	1,564,706	0
Embodied Energy of Materials Recycled	278,669	278,669	0
Embodied Energy of Liquid Waste System	2,021	2,021	0
Embodied Energy of Fuels - SW Operations	3,669	1,846	1,823
Embodied Energy of Fuels - LW Operations	2,085	1,132	953
Solid Waste Operations	9,750	9,750	0
Liquid Waste Operations	5,840	5,840	0
Total	**2,284,000**	**2,281,000**	**3,000**

CBEI of Transportation

The updates resulted in a net increase of emissions for transportation of 4.6% (Figure 4, Table 5, Table 7). The rise in transportation emissions due to the updated local factors for embodied emissions of fuels is actually 14.9%, but the updated embodied emissions of materials offset this with a decrease in transportation emissions of 9.8%. The embodied emissions of materials of vehicles are expected to continue to shift as more data becomes available, particularly the average lifespan of commercial vehicles, which is widely variable and not well documented. The lifespan of vehicles is important as it is used to allocate a portion of the total embodied emissions of materials of the vehicles to a single inventory year.

The addition of embodied emissions of materials for BC Ferries, West Coast Express and aircraft added just under 10,000 tCO_2e to the inventory which is only 0.08% of transportation emissions (Table 6).

The update in allocation of BC Ferries emissions, combined with the additional embodied emissions, resulted in a net decrease of just under 40,000 tCO_2e (Table 7). Approximately 40% of BC Ferries annual emissions are now allocated to the region whereas previously it was just over 50%.



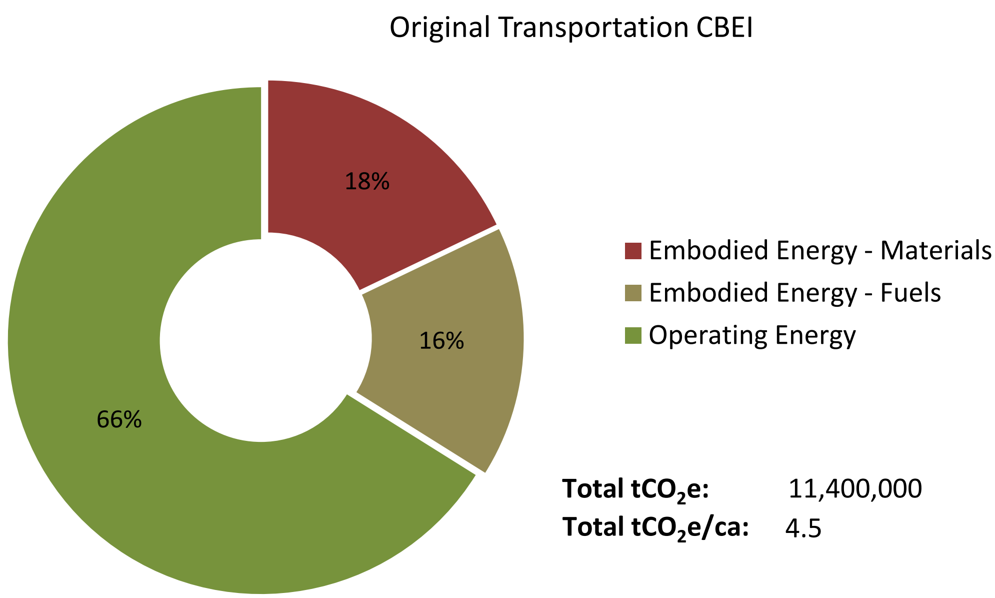


Figure 4: Updated & Original CBEI of Transportation for the Metro Vancouver Region, 2015

Table 5: Updated & Original CBEI of Transportation for the Metro Vancouver Region, 2015

	Updated CBEI (tCO_2e)	Original CBEI (tCO_2e)	Change
Embodied Energy - Materials	921,216	2,040,414	-1,119,198
Embodied Energy - Fuels	3,517,742	1,823,713	1,694,029
Operating Energy	7,480,049	7,535,808	-55,759
Total	**11,919,000**	**11,400,000**	**519,000**

Table 6: Updated & Original Embodied Emissions of Transportation for the Metro Vancouver Region, 2015

Embodied Emissions Only	Updated CBEI (tCO_2e)	Original CBEI (tCO_2e)	Change
Embodied Roads - Materials	125,025	125,025	0
Embodied Private Vehicles - Materials	546,218	1,397,284	-851,066
Embodied Commercial Vehicles - Materials	225,710	496,300	-270,590
Embodied Transit (City/School Bus, WCE) - Materials	9,667	10,657	-990
Embodied Intercity Bus - Materials	5,429	11,147	-5,718
Embodied BC Ferries - Materials	8,021		8,021
Embodied Air Travel - Materials	1,147		1,147
Embodied Private Vehicles - Fuels	1,859,827	941,450	918,377
Embodied Commercial Vehicles - Fuels	788,433	411,793	376,640
Embodied Transit (City/School Bus, Seabus, WCE) - Fuels	24,533	13,593	10,940
Embodied Intercity Bus - Fuels	22,992	12,763	10,229
Embodied BC Ferries - Fuels	47,085	36,824	10,261
Embodied Air Travel - Fuels	574,567	305,977	268,590
Embodied Off Road - Fuels	200,305	101,313	98,992
Total	**4,439,000**	**3,864,000**	**575,000**

Table 7: Updated & Original CBEI of Transportation, by Type for the Metro Vancouver Region, 2015

CBEI By Transportation Type	Updated CBEI (tCO_2e)	Original CBEI (tCO_2e)	Change
Roads	125,025	125,025	0
Private Vehicles	6,116,553	6,049,243	67,310
Commercial Vehicles	2,668,477	2,562,426	106,051
Transit (City & School Bus, Seabus, WCE)	91,159	81,209	9,950
Intercity Bus	81,505	76,994	4,511
BC Ferries	175,577	213,055	-37,478
Air Travel	2,061,307	1,791,571	269,736
Off Road and Street Lights	599,403	500,411	98,992
Total	**11,919,000**	**11,400,000**	**519,000**

CBEI of Water

The updates had a negligible impact on overall emissions for the water supply.

Table 8: Updated & Original CBEI of Water for the Metro Vancouver Region, 2015

	Updated CBEI (tCO_2e)	Original CBEI (tCO_2e)	Change
Water Supply Embodied - Materials	15,995	15,995	0
Water Supply Embodied - Fuels	708	365	343
Water Supply Operating Energy	2,170	2,170	0
Total	**19,000**	**19,000**	**0**

Ecological Footprint

The ecological footprint captures the majority of the emissions in the CBEI and converts them into a land equivalent based on the area needed to sequester these emissions; and it also includes the total built area. For example, for food (Figure 5, green), the ecological footprint includes the land required to sequester GHG emissions associated with producing and transporting food as well as the farmland required to produce the food.

The ecological footprint can be expressed in global hectares (gha)[2], and can also be expressed in number of 'Earths' by dividing the region's footprint by the total global biologically productive area.

The ecological footprint of the region is estimated at 3.6 gha/ca or 2.4 Earths (Figure 5). If the impacts from senior government services and infrastructure are included, the ecological footprint estimate increases to 6.4 gha/ca or 4.2 Earths (Table 9). This means that if everyone on the planet had the same impact as the average person living in Metro Vancouver then we would need at least 4.2 Earths to support them.

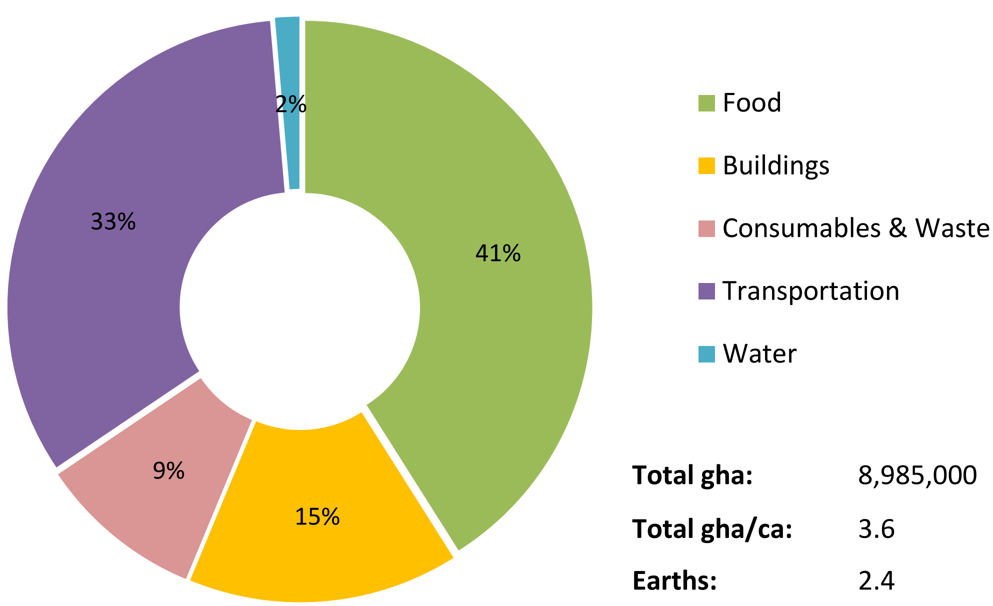


Figure 5: Ecological Footprint for the Metro Vancouver Region, 2015 (not including senior government)

[2] A global hectare is a hectare with a global average productivity.

Table 9: Ecological Footprint for the Metro Vancouver Region, 2015

	(gha)	(gha/ca)	Earths
Food	3,686,275	1.47	0.98
Buildings	1,369,480	0.54	0.36
Consumables & waste	835,317	0.33	0.22
Transportation	2,972,081	1.18	0.79
Water	122,334	0.05	0.03
Senior Government Impacts	6,976,628	2.77	1.85
Total	**15,962,115**	**6.4**	**4.2**

Methodology and Sources (Updated)

The following provides a detailed summary of the methodology, assumptions and sources utilized in creating the Metro Vancouver region's CBEI. It also presents challenges and opportunities associated with the data collection process.

Dr. Moore's ecoCity Footprint Tool has been used to generate this inventory. A detailed overview of the methodology employed in the ecoCity Footprint Tool to generate CBEIs and ecological footprint (EF) assessments is presented in Dr. Moore's PhD thesis: Moore, (2013). *Getting Serious About Sustainability: Exploring the Potential for One-Planet Living in Vancouver*. A thesis submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy, School of Community and Regional Planning, University of British Columbia. Available at: http://pics.uvic.ca/sites/default/files/uploads/publications/moore_jennie-UBC_0.pdf

The following presents the data sources, methods and assumptions applied in generating the Metro Vancouver region's CBEI.

Population

Population estimates for the region and for member communities were based on the region's 2015 territorial GHG emission inventory. The territorial inventory uses data from the 2016 census year adjusted for an undercount of 1.97%. Population for individual members of Electoral Area A were only available for 2011 and all growth to 2016 is assumed to have occurred in University of British Columbia and University Endowment Lands.

Sources

Data provided by staff from Metro Vancouver's 2015 Territorial GHG Emissions Inventory

Statistics Canada. (Feb 8, 2017). Focus on Geography Series, *2016 Census*. Retrieved from https://tinyurl.com/5aedvnbk

Food

Evaluates the embodied and operating energy associated with producing and transporting food. Statistics Canada data is utilized as a proxy for food consumption in the region and average import distances are used to estimate kilometers travelled.

Embodied Energy [Food Production] Methodology

Food consumption was estimated using Statistics Canada data from Table: 32-10-0054-01 which documents national 'food availability' per person by year (Statistics Canada, n.d.). Disaggregated food items are then organized into larger food groups to estimate average food consumption per-capita by food type. Life Cycle Assessment data was obtained from the CleanMetrics calculator. The data is 'cradle to farm gate', including, for example, emissions from soil management, fertilizer, and enteric fermentation. A more comprehensive methodology writeup is available at https://www.cleanmetrics.com/carbonscopedata/methodology.aspx

End of life food disposal impacts are accounted for in the emissions associated with landfills and biogas from solid and liquid waste treatment and ascribed to the consumables and waste component.

Sources

Statistics Canada. (n.d.). Table: 32-10-0054-01: Food available in Canada, annual (kilograms per person, per year unless otherwise noted). https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210005401

CleanMetrics, Food Carbon Emissions Calculator. http://www.foodemissions.com/Calculator

Challenges and Opportunities

The biggest challenge concerning food consumption is the lack of readily available data sources, since local governments have traditionally not tracked food-related data. As a proxy, national data from Statistics Canada is used to infer average consumption by food type. Accordingly, food consumption emissions represent national averages rather than local averages.

In the future local data could be generated by conducting research with food wholesalers and their retail distribution networks. Alternately, estimates could be derived through food surveys and/ or collection of data through self-reporting and tracking tools such as the Lighter Footprint App (LFA). However, the number of respondents would need to be statistically valid and representative in order to make inferences from survey results. Early work was conducted by City of Vancouver in 2019 to test a survey developed by Dr. Moore with support by Cora Hallsworth and Ryan Mackie.

The embodied emissions of some processed foods are captured in the CBEI, such as beverages, however, research needs to be done to capture more of these embodied emissions.

Embodied Energy of Fuels [Food Miles] Methodology

The embodied emissions of all fossil fuels (for example, from extraction and refining of the fuels) reported in operating emissions are included. 'Well to Tank' (WTT) emission factors are derived for local Canadian sources.

Liquid Fuels

WTT carbon intensities for gasoline, diesel, and jet fuels derived from the Canadian oil sands were published by the US Department of Energy. WTT factors for other liquid fuels, such as heating oil, were scaled from values published by the U.K. government using the factors for the Canadian oil sands. For example, the difference between standard diesel WTT factors for the U.K. and Canadian oil sands, was used to scale up the U.K. factor for heating oil to estimate a factor for heating oil derived from the Canadian oil sands.

Sources

US Department of Energy. (2009). An Evaluation of the Extraction, Transport and Refining of Imported Crude Oils and the Impact on Life Cycle Greenhouse Gas Emissions. Retrieved from https://d35t1syewk4d42.cloudfront.net/file/1599/An-Evaluation-of-the-Extraction-Transport-and-Refining-of-Imported-Crude-Oils-and-the-Impact-on-Life-Cycle-Greenhouse-Gas-Emissions-.pdf

Challenges and Opportunities

WTT factors for Canadian fuels are not widely available in the public domain. This is of particular concern since fuels derived from Canadian oil sands have much higher WTT emissions than global averages. The higher WWT factors used are appropriate for domestic transport of food in Canada, however they are likely to overpredict WTT emissions for imported food to Canada.

Operating Energy [Food-Miles] Methodology

Methodologies for determining average food-miles for food imported to Canada and for food transported domestically (within Canada) are different, as described below.

Operating Energy [Food-Miles, Food Imported to Canada] Methodology

To estimate distance travelled for food imported to Canada, a similar methodology was followed as outlined in Dr. Meidad Kissinger's *International Trade Related Food Miles – The Case of Canada* (2012). Data is obtained from the Canadian CHASS (Computing in Humanities and Social Sciences) *Trade Analyzer Database*. The database tracks Canadian import totals based on *Harmonized System* (HS) 10-digit merchandise codes by origin (country or US state) and province of clearance.

Distance Calculations

Two types of distances were considered, land and sea. Where available, road distances were used for North American destinations and more specifically, the distance between the most populous city in each province and state were used. Road distances were taken from online North American Mileage Charts whereas all other imports were assumed to be transported by sea. The *Sea Distance/ Port Distances* online tool, available on Sea-Distances.org, was used to calculate distances between seaports. Where available, the major seaport was used for each origin or destination. Inland countries' imports were assumed to be trucked to the closest major seaport and shipped by sea. Accordingly, inland countries without a major seaport used the distance to the closest seaport in a neighbouring country. Import by air is omitted; this is anticipated to affect mostly short shelf-life products such as fruit, vegetables and seafood.

Percent Imports by Destination

Canadian imports for the latest available year at the time of the study (2013) was exported and organized into broader food categories to align with food consumption data. Based on the total quantity of imports, the percent of food imports by category and origin destinations was calculated. For example, 4.32% of Canada's total wine imports were imported from Australia into Ontario. A matrix of food category import percentages by origin and province of clearance was created.

Average Food-Miles

An average import distance was determined for each specific category, separated by road and by sea, using a weighted average. Each individual import percentage by food category, destination, and origin, was multiplied by the respective road or sea distance. Using the same example as above, the percent of total wine imports from Australia to Ontario was multiplied by the assumed sea distance (20,618 km x 4.32% = 866 km). The sum of each food category's weighted distances by destination and origin was taken as the average import distance.

Percent Scale for Imports

With an average import distance for food categories calculated, a percent import scale factor was applied which averaged out the imported sea and road distances across the entire food category population. Percent imports were calculated by analyzing data from Table: 32-10-0053-01, which documents the imports and total supply for food categories by year (Statistics Canada, n.d.).

Sources

Kissinger, M. (2012). International trade related food miles: The case of Canada. *Food Policy, 37*(2), 171-178. doi:10.1016/j.foodpol.2012.01.002

Mileage-Charts. (n.d.). Retrieved August 2017, from http://www.mileage-charts.com/chart.php?p=index&a=NA

SEA-DISTANCES.ORG. (n.d.). *Sea Distance/ Port Distances*. Retrieved September 2017, from https://sea-distances.org/

Statistics Canada. (n.d-a). *Table: 32-10-0053-01: Supply and disposition of food in Canada, annual (tonnes unless otherwise noted)*. Retrieved on September 17, 2017, from http://www5.statcan.gc.ca/cansim/a47

Statistics Canada. (n.d.-b). *Table: 32-10-0054-01*: Food available in Canada, annual (kilograms per person, per year unless otherwise noted). Retrieved May 11, 2017, from http://www5.statcan.gc.ca/cansim/a47

Weber, C.L., Matthews, S.H. (2008). Food-miles and the relative climate impacts of food choices in the United States. *Environmental Science & Technology*, *42*, 3508–3513.

Challenges and Opportunities

HS merchandise codes for meat and eggs were not available in the database used for this inventory. Import distances for these foods were derived from Meidad Kissinger's *International Trade Related Food Miles – The Case of Canada* (2012).

Similar to food consumption, the biggest challenge relating to evaluating food miles is the lack of readily available data sources. Quantifying food miles can be difficult and relies on the combination of several data sets to produce estimates. National Canadian import data was used to approximate average, representative distances for the entire food category which limits insights from food miles to a national scale.

Using Canadian imports sorted on the 10-digit HS system, it was possible to quantify imports and their origins and destinations at a granular level.

One limitation of the available data is that some (unknown) portions of specific food types may not be associated with consumption (for example, wheat for sowing). Additionally, it is assumed that the transported distances for food items are similar between food for consumption and production.

Only transport by road and sea are included in the inventory. Transport by train is estimated to represent 7% of food movements (Kissinger, 2012) which is relatively minor. The use of air transport for food is also low, however, associated emissions with air transport are significantly higher on a per tonne-km basis than those associated with truck or sea distances (Weber and Matthews, 2008). For this reason, air imports should be considered in food calculations even though they represent a small portion of total food imports.

Averaged road and sea distances for Canadian imports are scaled by percent import factors for each food category. This scaling to determine overall average distances introduces uncertainties.

Operating Energy [Domestic Food-Miles] Methodology

To estimate distance travelled for food produced domestically (within Canada), statistics on food production and/or processing locations was used, in combination with statistics on British Columbia supply and interprovincial trade of each food type. Metro Vancouver BC was used as the destination for domestic food transport.

Distance Calculations

Data from Statistics Canada (e.g. Census of Agriculture), various industry reports and market research were used to find key geographical areas of production and/or processing for each food category across Canada. Google Maps was used to estimate distances by road from each production and/or processing area to a central point in Metro Vancouver BC (New Westminster).

Weighted Average Food-Miles

Statistics Canada 'Supply and Use' tables for British Columbia, various industry reports and market research were used to calculate the percentage of BC supply coming from each province for each food type. These percentages were used to scale the transport distances to calculate a weighted average distance for each food type for the total of all production and/or processing areas across Canada. For example, 91% of BC's beef is supplied from other provinces with import distances (to Metro Vancouver) ranging from about 1,100 km for beef sourced from Alberta to 5,700 km for Nova Scotia. By far the highest percentage of imports to BC are from Alberta, resulting in a weighted average interprovincial import distance of about 1,500 km. Beef raised in BC would travel a weighted average of 730 km, and accounts for only 7% of BC's supply. This results in an overall weighted average of about 1,400 km for domestic transport of beef to the Metro Vancouver area.

Sources

Agriculture and Agri-Food Canada. (n.d.). Canadian Cheese Manufacturers Directory. Retrieved from https://cheese-fromage.agr.gc.ca/pml-lmp_eng.cfm?menupos=1.3

British Columbia Farm Industry Review Board. (2017). BC Hog Industry Snapshot. Retrieved from https://www2.gov.bc.ca/assets/gov/british-columbians-our-governments/organizational-structure/boards-commissions-tribunals/bc-farm-industry-review-board/regulated-marketing/2017_hog_industry_snapshot_bcfirb.pdf

Canola Council of Canada. (n.d.). Industry Overview. Retrieved from https://www.canolacouncil.org/about-canola/industry/

Dun & Bradstreet. (n.d.). Beverage manufacturing in Canada. Retrieved from https://www.dnb.com/business-directory/company-information.beverage_manufacturing.ca.html

Fisheries and Oceans Canada. (2020). Aquaculture in British Columbia. Retrieved from https://www.dfo-mpo.gc.ca/aquaculture/bc-cb/maps-cartes-eng.html

Metro Vancouver. (2020). Food flows in Metro Vancouver. Retrieved from http://www.metrovancouver.org/services/regional-planning/PlanningPublications/FoodFlowsinMetroVancouver.pdf

Pitcher, Tony & Buchary, Eny & Sumaila, Rashid. (2002). A Synopsis of Canadian Fisheries. Retrieved from https://www.researchgate.net/figure/The-top-ten-fisheries-landing-ports-in-Canadian-Pacific-fisheries-ranked-according-to_fig2_276205343

Statistics Canada. (2016, 2011). Census of Agriculture (multiple tables). Retrieved from https://www150.statcan.gc.ca/n1/en/type/data?subject_levels=32&geoname=A0002%2CA0003%2CS0501%2CS0502&sort=releasedate&count=100

Statistics Canada. (2016). Census of Agriculture Reference Maps. Retrieved from https://www150.statcan.gc.ca/n1/pub/95-630-x/95-630-x2017000-eng.htm

Statistics Canada. (2014). Pulses in Canada. Retrieved from https://www150.statcan.gc.ca/n1/pub/96-325-x/2014001/article/14041-eng.htm

Statistics Canada. (2017). Supply and Use Tables, 2017. Retrieved from https://www150.statcan.gc.ca/n1/pub/15-602-x/15-602-x2017001-eng.htm

Challenges and Opportunities

In the analysis of food miles, it was necessary to find information on some food types that are not tracked in Statistics Canada's 'Supply and Use' tables and/or in the Census of Agriculture tables. Gaps were filled using various industry reports and market research.

Transport distances were estimated using suggested road routes by Google Maps. The actual routes and transport mode may differ.

Only transport by road is included in the inventory. Transport by train is estimated to represent 7% of food movements (Kissinger, 2012) which is relatively minor. The use of air transport for food is also low. However, emissions associated with air transport are significantly higher on a per tonne-km basis than those associated with truck or sea distances (Weber and Matthews, 2008). For this reason, air imports should be considered in food calculations even though they represent a small portion of total food transport.

Emission Factors and Final Calculation for Food Miles

Emission factors for freighting goods are published by the UK government in the form of $kgCO_2e$/tonne-km. For each food type these factors are multiplied by the combined average imported and domestic transport distances (described above) and the total tonnes consumed (described in the Food Production Methodology section).

Sources

UK Government: Department for Business, Energy & Industrial Strategy (July 17 2020). *Greenhouse gas reporting: conversion factors 2020*. Retrieved from https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020

Buildings and Stationary Energy

The embodied and operating energy of buildings and stationary energy uses associated with residential, institutional and commercial buildings is estimated in order to establish the direct and embodied GHG emissions attributable to buildings.

Embodied Energy of Materials [Buildings and Stationary Energy] Methodology

The gross floor area of commercial, institutional, and residential buildings as well as an estimated composition of each building type are required to evaluate the embodied materials associated with the building stock. Residential units are divided into categories depending on building types (e.g., single family detached house, high-rise apartment, etc.). Commercial and institutional buildings are differentiated based on their material composition (e.g., wood frame, steel/concrete frame)

The ecoCity Footprint Tool contains calculations and assumptions to derive the embodied materials and energy associated with the total materials contained within the buildings, which were developed through Dr. Moore's original ecological footprint study of the City of Vancouver, and are summarized in Dr. Moore's 2013 thesis. The Tool employs embodied emission factors by building archetype, derived from the Athena Impact Estimator for Buildings Tool and a set of building archetypes for the Metro Vancouver region. The average lifespan of buildings was assumed to be 40 years for wood frame buildings and 75 years for concrete/steel frame buildings, based on data provided by Metro Vancouver. These values fall within the Canadian Standards Association Guideline on Durability in Buildings as referenced by Metro Vancouver's Build Smart program (GVRD 2001).

Sources

Gross floor area data was provided by Metro Vancouver staff

GVRD (2001) Best Practices Guide: material choices for sustainable design. Metro Vancouver, Burnaby BC

Moore, J., Kissinger, M., & Rees, W. E. (2013) An urban metabolism and ecological footprint assessment of Metro Vancouver. *Journal of Environmental Management, 124*, 51-61.

Challenges and Opportunities

Estimates for building lifespan have a large impact on embodied energy estimates and there is likely variation across the region.

The embodied emissions associated with maintenance, renovations and furniture over the lifespan of buildings are not included in calculations. There is limited research on these impacts; however, it suggests the impacts may more than double the embodied emissions for buildings.

Embodied Energy of Fuels [Buildings and Stationary Energy] Methodology

The embodied emissions of all fossil fuels (for example, from extraction and refining of the fuels) reported in operating emissions are included. 'Well to Tank' (WTT) emission factors are derived for local Canadian sources.

Note that fugitive emissions of natural gas networks that are typically reported in territorial inventories are included within the factors for embodied emissions of fuels used in the CBEI.

Natural Gas

WTT carbon intensities including gas production, processing, and pipeline transport are published by Fortis. However, recent studies (2021) have shown that fugitive emissions are being underreported. Discussions with the BC Climate Action Secretariat suggest that future reporting requirements will likely take these findings into account. Therefore, the fugitive emissions reported by Fortis were scaled up to account for the suspected underreporting.

Liquid Fuels

WTT carbon intensities for gasoline, diesel, and jet fuels derived from the Canadian oil sands were published by the US Department of Energy. WTT factors for other liquid fuels, such as heating oil, were scaled from values published by the U.K. government using the factors for the Canadian oil sands. For example, the difference between standard diesel WTT factors for the U.K. and Canadian oil sands, was used to scale up the U.K. factor for heating oil to estimate a factor for heating oil derived from the Canadian oil sands.

Sources

David R. Tyner and Matthew R. Johnson. (2021). Where the Methane Is - Insights from Novel Airborne LiDAR Measurements Combined with Ground Survey Data. *Environmental Science & Technology*, 55 (14), 9773-9783. doi:10.1021/acs.est.1c01572. Retrieved from https://pubs.acs.org/doi/pdf/10.1021/acs.est.1c01572

FortisBC. (2020). Life Cycle GHG Emissions of the LNG Supply at the Port of Vancouver. Retrieved from https://www.cdn.fortisbc.com/libraries/docs/librariesprovider5/sustainability-in-all-we-do/lifecycle-ghg-emissions-of-the-lng-supply-at-the-port-of-vancouver-footnote-8.pdf?sfvrsn=9a964ce7_0

US Department of Energy. (2009). An Evaluation of the Extraction, Transport and Refining of Imported Crude Oils and the Impact on Life Cycle Greenhouse Gas Emissions. Retrieved from https://d35t1syewk4d42.cloudfront.net/file/1599/An-Evaluation-of-the-Extraction-Transport-and-Refining-of-Imported-Crude-Oils-and-the-Impact-on-Life-Cycle-Greenhouse-Gas-Emissions-.pdf

Challenges and Opportunities

WTT factors for Canadian fuels are not widely available in the public domain. This is of particular concern since fuels derived from Canadian oil sands have much higher WTT emissions than global averages.

Operating Energy [Buildings and Stationary Energy] Methodology

To calculate operating energy, data is required on the annual consumption of electricity, natural gas, and other heating fuels; broken down by sector. Energy lost through transmission is also collected or estimated. GHG emissions are then calculated using provincially specified emissions factors or emission factors used in data provided by staff from Metro Vancouver's 2015 Territorial GHG Emissions Inventory.

Stationary Energy and Transmission Loss

Stationary energy use data for the region, broken down by member communities was available from data provided by staff from Metro Vancouver's 2015 Territorial GHG Emissions Inventory and BC Hydro. BC Hydro's estimated transmission loss rate of 10% was applied to account for emissions associated with electricity transmission losses.

Sources

Data provided by staff from Metro Vancouver's 2015 Territorial GHG Emissions Inventory

BC Hydro data provided by Metro Vancouver staff

BC Ministry of Environment. (2014). 2014/15 B.C. best practices methodology for quantifying greenhouse gas emissions: Including guidance for public sector organizations, local governments and community emissions. Retrieved from http://www2.gov.bc.ca/assets/gov/environment/climate-change/cng/methodology/2014-15-pso-methodology.pdf

Consumables and Waste

The embodied and direct emissions associated with waste disposal and the embodied and operating emissions from waste facility operations is estimated.

Data is collected on:

- the type and quantity of solid and liquid waste generated in the region by sector (residential, commercial and institutional) and by material type;
- the method by which these materials are managed (i.e., landfilled, incinerated, recycled, composted, or treated);
- the energy consumption and emissions associated with the waste management facilities, and the transport of wastes.

Materials Disposed, Embodied Energy of Materials and Fuels, and Operating Energy [Consumables and Waste] Methodology

The emissions associated with 'materials disposed' and 'embodied energy of materials' represent the GHG impacts at end-of-life and beginning-of-life respectively. Embodied emissions are calculated using LCA data. Direct emissions of 'materials disposed', (associated with landfilling, composting, and incinerating) include:

- For incineration and composting - emissions are, for the most part, associated with materials disposed in the given inventory year.

- For landfilling - emissions for a given year - these emissions are primarily from waste disposed in previous years that decay over many years. This approach works well for an established landfill and waste stream that is in a steady state in which the annual cumulative emissions of the landfill reflect the emissions that will occur in the future for the waste disposed in a given inventory year.

Solid waste data is collected as disaggregated data, by sector, material type and destination (i.e., landfill, incineration, composting, or recycling. The Metro Vancouver 2017 Biennial 5 Year Progress Report and 2015 Waste Composition Monitoring Report contain the total tonnage for the metro region and the breakdown of waste by source type (single and multi-family residential, demolition, ICI) as well as by material type.

Recycling tonnages data came from the Metro Vancouver Recycling and Solid Waste Management Annual Report for 2015. Composition of the recyclable stream was based on regional averages, as presented in Metro Vancouver's Waste Composition Report for the same year.

Direct emissions associated with the Vancouver landfill and waste-to-energy facility were obtained from data provided by staff from Metro Vancouver's 2015 Territorial GHG Emissions Inventory. Emissions associated with the Cache Creek landfill were obtained from the Metro Vancouver 2017 Biennial 5 Year Progress Report. Emissions associated with composting were calculated using 2006 IPCC Guidelines.

The embodied emissions of materials disposed and recycled, meaning the emissions associated with the supply chains of consumable goods (production and shipping), are estimated using lifecycle assessment data combined with the tonnage of each material type disposed. Lifecycle assessment data was compiled as part of Dr. Moore's PhD research by a research assistant, and subsequently published (Kissinger et al. 2013a; Kissinger et al. 2013b). The GHG factors were derived from literature. Material tonnages are estimated from total solid waste tonnage and the waste composition found in the 2015 Waste Composition Monitoring Report.

The embodied emissions of fuels are calculated as described in 'Embodied Fuels [Buildings and Stationary Energy] Methodology' above.

Direct emissions from the liquid waste stream were obtained from data provided by staff from Metro Vancouver's 2015 Territorial GHG Emissions Inventory

Solid and liquid waste operations data was obtained from data provided by staff from Metro Vancouver's 2015 Territorial GHG Emissions Inventory. GHG emissions were then calculated using provincially specified emissions factors.

The embodied emissions of sanitary sewer and storm sewer drainpipes were undertaken as part of Dr. Moore's PhD research. GHG emissions factors were developed based on Life Cycle Data compiled from the literature by a research assistant who then applied them according to pipe lengths, dimensions, diameters and material properties, based on available data from Metro Vancouver (i.e., Greater Vancouver Sewerage and Drainage District) and the City of Vancouver. This research was not subsequently published (see reference to Giratalla below).

Sources

Data provided by staff from Metro Vancouver 2017 Biennial 5 Year Progress Report

Data provided by staff from Tetra Tech. 2015 Waste Composition Monitoring Program. Jan 2016

Data provided by staff from Metro Vancouver Recycling and Solid Waste Management 2015

Data provided by staff from Metro Vancouver's 2015 Territorial GHG Emissions Inventory

Data provided by staff from Metro Vancouver 2015 Corporate GHG Inventory

2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5, Chapter 4: Biological Treatment of Solid Waste

BC Ministry of Environment. (2014). 2014/15 B.C. best practices methodology for quantifying greenhouse gas emissions: Including guidance for public sector organizations, local governments and community emissions. Retrieved from http://www2.gov.bc.ca/assets/gov/environment/climate-change/cng/methodology/2014-15-pso-methodology.pdf

Giratalla, W. (unpublished) Embodied Energy Summary Packaged Files - Embodied Energy of GVRD Pipes, supplementary data files comprising part of the research project for J. Moore. (2013) Getting Serious About Sustainability: Exploring the Potential for One Planet Living in Vancouver. A thesis submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy, School of Community and Regional Planning, University of British Columbia

Kissinger, Meidad; Cornelia Sussmann; Jennie Moore; William E. Rees. 2013a. Accounting for the Ecological Footprint of Materials in Consumer Goods at the Urban Scale. *Sustainability,* 5(5): 1960-1973.

Kissinger, Meidad; William E. Rees; Cornelia Sussmann; Jennie Moore. 2013b. Accounting for Greenhouse Gas Emissions of Materials at the Urban Scale- Relating Existing Process Life Cycle Assessment Studies to Urban Material and Waste Composition. *Low Carbon Economy*, 4(1): 36-44.

Moore, J. (2013) *Getting Serious About Sustainability: Exploring the Potential for One-Planet Living in Vancouver*. PhD Thesis. University of British Columbia. (For LCA data)

Challenges and Opportunities

Data on the energy used at Cache Creek and/or generated by Harvest Power have not been collected.

Impacts from consumables are not amortized over an average lifespan as is done with the embodied emissions of materials for other categories, such as buildings, roads, vehicles, etc. Instead, it is assumed that the rate of disposal is consistent with the rate of consumption of new products and that the average lifespan will be accounted for in these rates on a community-wide and year-over-year basis.

LCA factors for consumables account for transport of materials. In the CBEI for food these emissions are reported separately. Further research could be done to extract the transport emissions from the LCA factors and report as 'consumable-miles' to be consistent with food-miles.

Life cycle assessment values are not available in the ecoCity Footprint Tool for all recycled material types in the Metro Vancouver region. Only recycled paper, plastic, glass, and metal are included in the inventory, as these were the dominant recycled material flows at the time of Moore's original research (See Appendix C, Table 4 for details). In 2015 these materials account for 46% of the total recycled tonnage in the region. Further research will need to be done to add additional factors.

Transportation

Evaluates the embodied emissions of the road network, private and commercial vehicle materials, embodied emissions of fuels and operating emissions (fuel consumed by vehicles, vessels and equipment).

Embodied Energy of Materials [Transportation] Methodology

Embodied emissions of materials used for roadways, on-road vehicles, BC Ferries, Rail (West Coast Express), and Aircraft are included.

The quantity of roadway and the road material composition is used along with LCA data to evaluate the embodied emissions of roads. Road lane kilometers for the region were scaled by population from a previous study completed for Surrey. The Surrey study was based on road lane lengths available from City GIS data and embodied energy factors developed through Dr. Moore's PhD research.

Factors for calculating embodied emissions of on-road vehicle materials are available in LCA literature. Averages of factors in several LCA studies were used for each vehicle type.

There are few LCA studies for specific marine vessels and rolling stock for rail. For both BC Ferries and rail (West Coast Express), average factors in "tCO2e/tonne steel" were applied.

LCA studies for aircraft commonly used for commercial flights are available in literature. The average of 5 common commercial aircraft are applied as a factor in "tCO2e per passenger kilometer".

Sources

City of Surrey GIS data available online

Geyer, R. (2018). UCSB Automotive Materials Energy and Green House Gas (GHG) Comparison Model. Retrieved from https://www.worldautosteel.org/life-cycle-thinking/

Giratalla, W. (unpublished). *Embodied Energy Summary Packaged Files - Embodied Energy of GVRD Roads*, supplementary data files comprising part of the research project for J. Moore. (2013) *Getting Serious About Sustainability: Exploring the Potential for One Planet Living in Vancouver*. A thesis submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy, School of Community and Regional Planning, University of British Columbia

Gratsos, G.A. & Psaraftis, Harilaos & Zachariadis, P. (2010). Life-cycle CO2 emissions of bulk carriers: A comparative study. Transactions of the Royal Institution of Naval Architects Part A: *International Journal of Maritime Engineering*. 152. A119-A134. 10.3940/rins.ijme.2010.a3.176. Retrieved from https://www.researchgate.net/publication/286979292_Life-cycle_CO2_emissions_of_bulk_carriers_A_comparative_study

International Council on Clean Transportation. (2021). A global comparison of the life-cycle greenhouse gas emissions of combustion engine and electric passenger cars. Retrieved from https://theicct.org/wp-content/uploads/2021/07/Global-Vehicle-LCA-White-Paper-A4-revised-v2.pdf

Kärnä, Päivi. (2012). Carbon footprint of the raw materials of an urban transit bus: case study: diesel, hybrid, electric and converted electric bus. Retrieved from https://www.researchgate.net/publication/263429106_Carbon_footprint_of_the_raw_materials_of_an_urban_transit_bus_case_study_diesel_hybrid_electric_and_converted_electric_bus/citation/download

L. Zhu, N. Li, P.R.N. Childs. (2018). Light-weighting in aerospace component and system design. *Propulsion and Power Research*, Volume 7, Issue 2, 2018, Pages 103-119. Retrieved from https://www.sciencedirect.com/science/article/pii/S2212540X18300191

Ticiano, Costa & Jordão, Ticiano. (2013). Life Cycle Assessment oriented to climate change mitigation by aviation. Retrieved from https://www.researchgate.net/publication/261403034_Life_Cycle_Assessment_oriented_to_climate_change_mitigation_by_aviation

Simonsen, M. (2009). Energy Requirements and Co2-Emissions from Manufacturing and Maintenance of Locomotives and Trains. Retrieved from http://sip1.vestforsk.no/pdf/Jernbane/TrainManufacturing.pdf

Challenges and Opportunities

Estimates of embodied emissions of materials for Seabus, off road vehicles and equipment, Skytrain and other infrastructure are not included in the inventory. Based on analysis of LCA data of West Coast Express it was found that impacts from Skytrain would be negligible over its lifespan.

Large portions of city surfaces are paved, yet their surface materials are not consistently, uniformly, or currently listed and tracked across jurisdictions. Paved or impermeable surfaces represent a significant source of CO_2.

Embodied Energy of Fuels [Transportation] Methodology

The embodied emissions of fuels are calculated as described in 'Embodied Energy of Fuels [Buildings and Stationary Energy] Methodology' above.

Operating Energy [Transportation] Road and Rail Transportation

Private and Commercial Vehicles

Emissions data by vehicle type was obtained from data provided by staff from Metro Vancouver's 2015 Territorial GHG Emissions Inventory. Vehicles were further grouped into private and commercial using 2015 ICBC vehicle registration data.

Transit

Emissions data for transit and school buses were obtained from data provided by staff from Metro Vancouver's 2015 Territorial GHG Emissions Inventory. West Coast Express emissions were obtained from a Railway Association of Canada report and allocated to the Metro Vancouver region based on station location (not including Vancouver) – 6 of the 7 stations are within the region meaning $6/7^{ths}$ of their reported emissions are included in the CBEI.

Off road vehicles

Emissions from off-road vehicles and equipment were obtained from data provided by staff from Metro Vancouver's 2015 Territorial GHG Emissions Inventory.

Sources

Data provided by staff from Metro Vancouver's 2015 Territorial GHG Emissions Inventory

Data provided by staff from ICBC 2015 Vehicle Registration Data for the Metro Vancouver region

Railway Association of Canada (2014) Local Emissions Monitoring program, retrieved from https://www.railcan.ca/wp-content/uploads/2017/03/2014_LEM_Report.pdf

Challenges and Opportunities

The TransLink Trip Diary survey used in this inventory only accounts for in-boundary vehicle emissions, however a CBEI should account for all vehicle emissions including out-of-boundary travel. Total vehicle emissions for a CBEI could be derived from annual odometer readings by vehicle type - collected during vehicle insurance renewals by ICBC. But given that these readings are not currently available, an alternative to the methodology used in the current study could be pursued.

Specifically, instead of using 'ICBC vehicle registration data' and 'average vehicle trip length' to calculate emissions it is likely more accurate to use the TransLink Trip Diary for both the 'number of trips by vehicle type' and 'average vehicle trip length' (or better yet, 'average vehicle trip length by vehicle type'). This methodology would eliminate overestimates of emissions from infrequently used vehicles which could be a source of error when using ICBC registration data with the TransLink Trip Diary. Additional questions may need to be added to the Trip Diary to enable use of this data; this method could be investigated for future inventories.

Marine Transportation Methodology

Marine transportation includes private vessels and passenger ferries. Private vessels are included in off-road emissions as they are in the Metro Vancouver 2015 Territorial GHG Emissions Inventory.

Two methods were used to estimate allocation of emissions of BC Ferries. The first used data from a 2006 BC Ferries passenger origin study and total reported fleet emissions. The second involved a detailed analysis of each BC Ferries route and vessel to allocate emissions. BC Ferries total fuel use for each route was derived from BC Ferries reports. Passenger trips per month, by route, were obtained from BC Ferries reports and used to estimate trips by locals versus tourists by comparing average winter and summer passenger trips. Additional data from tourism industry reports provided an estimate of the percentage of tourists using BC Ferries that are residents of BC. Emissions associated with regular ferry use by locals was allocated based on the primary regions served by each route and whether one of the regions acts as an urban center. For example, the portion of Route 1 emissions attributed to local use is split equally between CRD and the Lower Fraser Valley. Whereas the portion of Route 8 emissions attributed to local use is all allocated to Bowen Island as it is primarily islanders regularly using the ferry to access the Lower Mainland. Emissions associated with ferry use by BC tourists are allocated on a per capita basis. There is good agreement between the two methodologies, however, the 2006 BC Ferries passenger origin study used in the first method above, only lists usage aggregated by Vancouver Island, Lower Mainland, and Gulf Islands.

2015 fuel use for the Seabus was provided by TransLink staff and 100% of emissions allocated to Metro Vancouver.

Sources

BC Ferries. (n.d.). Policies, reports and plans (multiple). Retrieved from https://www.bcferries.com/in-the-community/resources

BC Ministry of Environment. (2014). *2014/15 B.C. best practices methodology for quantifying greenhouse gas emissions: Including guidance for public sector organizations, local governments and community emissions*. Retrieved from http://www2.gov.bc.ca/assets/gov/environment/climate-change/cng/methodology/2014-15-pso-methodology.pdf

CRD. (2008). Southern Gulf Islands Community Tourism Study. Table 9. Retrieved from https://www.crd.bc.ca/docs/default-source/salt-spring-island-ea-pdf/cedc/part_one-tourism_profile.pdf?sfvrsn=2

Destination BC. (2017). Vancouver Island Regional Tourism Profile. Retrieved from https://www.destinationbc.ca/content/uploads/2018/05/Vancouver-Island-Regional-Tourism-Profile_2017.pdf

Seabus 2015 fuel use provided by TransLink staff

Challenges and Opportunities

Cruise ship activities could be included with survey data on regional use globally.

Air Travel Methodology (YVR)

Metro Vancouver regional residential air travel was estimated using average per-capita values for the region based on a modified methodology described in *A Greenhouse Gas Emissions Inventory and Ecological Footprint Analysis of Metro Vancouver Residents' Air Travel* (Legg et al., 2013).

Air travel data was provided by the Vancouver International Airport (YVR) organized by destination. The total number of inbound and outbound flights were sorted into four categories:

1. International
2. International – United States
3. Domestic – Flights within Canada
4. Commuter – Flights within British Columbia

Seat Class

YVR provided the total number of seats per flight. Where available, a breakdown of seat classes was provided. Using these numbers, average factors for seat class breakdowns were generated based off of flight type (International, International – United States, and Domestic) and plane size (total seats). These factors were then used to estimate the number of seats by class for flights that did not provide disaggregated seat data.

Average Load Factor

Since YVR does not collect passenger numbers per flight, average flight load factors were applied to the total number of seats per flight to estimate passenger movements. Based on YVR estimates, their average load factor in 2015 was 82%. For reference, this load factor was compared to national averages for major Canadian airlines listed as Level IA, which means the airline's transported passenger revenues were at least ten million. Air Canada's 2015 load factor was 84%, and WestJet's 2015 load factor was 80% (Statistics Canada, 2016).

Distance and Emission Calculation

The Great Circle Distance was used to estimate flight distances to and from each destination using the World Airport Codes web tool. For cities with multiple airports that did not specify the specific airport, the largest airport for the city was used. These flight distances were then multiplied by the number of passengers by seat class per destination to estimate total passenger-kilometers by flight and seat classification. Then, air emission factors based on flight distance and seat class from the United Kingdom Department for Environment, Food & Rural Affairs (UK DEFRA) were applied to convert passenger-km to tCO_2e (UK DEFRA, 2016).

Metro Vancouver Regional Residential Scale Factor

Finally, a load factor of 0.20 was used to scale YVR's total flights for Metro Vancouver Residents. YVR demographic analysis from 2015 indicates that approximately 20% of flights are attributable to Metro Vancouver residents (J. Aldcroft, Manager, Environment, YVR, personal communication, August 22, 2017).

Methodology (Other Airports)

Emissions for the Abbotsford International Airport (YXX) are scaled from YVR using turboprop and commercial jet movements for domestic and international flights. These aircraft make up about 90 percent of YVR movements, therefore YVR emissions can only be used as a proxy for them. Turboprop and commercial jets only make up 26% of YXX movements, but would make up a much larger portion of total emissions due to their larger size and flight distance than other YXX aircraft. 50 percent of YXX emissions are allocated to Metro Vancouver residents.

Emissions from other smaller airports within the region cannot be scaled. For these airports landing and takeoff (rather than total flight distance) emissions from Metro Vancouver's 2015 Territorial GHG Emissions Inventory are included in the inventory with 100% of emissions allocated to regional residents.

Sources

Air travel data for YVR was provided by the Vancouver International Airport (YVR) staff

Legg, R., Moore, J., Kissinger, M., & Rees, W. (2013). A greenhouse gas emissions inventory and ecological footprint analysis of Metro Vancouver residents' air travel. *Environment and Pollution, 2*(4). doi:10.5539/ep.v2n4p123

Statistics Canada. (n.d.). Table 401-0043: Operational statistics for major Canadian airlines, level IA, by airline, monthly*, CANSIM*. Retrieved on October 14, 2017, from http://www5.statcan.gc.ca/cansim/a47

UK DEFRA. (June 2016). Greenhouse gas reporting: Conversion factors 2016. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/526958/ghg-conversion-factors-2016update_MASTER_links_removed_v2.xls

Data provided by staff from Metro Vancouver 2015 Territorial GHG Emissions Inventory

Challenges and Opportunities

YVR's estimates are limited by four main constraints.

YVR can only provide flight data to and from flights based off their first destination. This overlooks air emissions associated with Metro Vancouver residents on connecting flights. For example, domestic flight emissions represent 32.4% of total air travel emissions, while international flights (excluding to the United States) account for 39.8% of air travel emissions. A number of these domestic flights are much more likely to be flights to Canadian cities connecting to international destinations, and as such the second leg of air travel is not estimated.

Second, these estimates do not account for Metro Vancouver residents who may drive to and from other airports (Bellingham, WA) for outbound and inbound flights. With high volumes of air traffic served by YVR, this may not represent a significant omission, but it does present an area for future research and consideration.

Third, the introduction of the 82% average flight load factor and 20% scale for residential emissions introduces scaling uncertainties into the last points of emission calculations.

CBEI emissions for both YXX and other smaller airports will be significantly underestimated using the methods employed. Further study of airport data would be needed to more accurately capture each airport's unique aircraft fleet, flight distances, and emissions allocation to the region.

Water

Evaluates the embodied energy and operating energy of the water purification and distribution system relied on by the region.

Embodied Energy of Materials [Water] Methodology

Concrete used in dams, road kilometers and pipe length were provided by Metro Vancouver staff. Additional pipe length and embodied energy factors were developed through Dr. Moore's original ecological footprint study of the City of Vancouver as part of Dr. Moore's 2013 thesis. The emission factor for concrete was obtained from literature.

Sources

Data provided by Metro Vancouver staff

Fowler and Sanjayan. 2007. Greenhouse Gas Emissions due to Concrete Manufacture. Journal of Lifecycle Assessment. 12(5): 282-288.)

Giratalla, W. (unpublished) Embodied Energy Summary Packaged Files - Embodied Energy of GVRD Pipes, supplementary data files comprising part of the research project for J. Moore. (2013) Getting Serious About Sustainability: Exploring the Potential for One Planet Living in Vancouver. A thesis submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy, School of Community and Regional Planning, University of British Columbia

Embodied Energy of Fuels [Water] Methodology

The embodied emissions of fuels are calculated as described in 'Embodied Fuels [Buildings and Stationary Energy] Methodology' above.

Operating Energy [Water] Methodology

Operating energy data was obtained from Metro Vancouver's 2015 Corporate GHG Inventory and Provincial emission factors used.

Sources

Data provided by staff from Metro Vancouver's 2015 Territorial GHG Emissions Inventory

BC Ministry of Environment. (2014). 2014/15 B.C. best practices methodology for quantifying greenhouse gas emissions: Including guidance for public sector organizations, local governments and community emissions. Retrieved from http://www2.gov.bc.ca/assets/gov/environment/climate-change/cng/methodology/2014-15-pso-methodology.pdf

Disaggregation of Emissions to Member Communities

Regional emissions for Food, Consumables and Waste, and Water are allocated to Metro Vancouver communities by population. Allocation methodology for Buildings and Transportation follow.

Buildings

Embodied and Operating Energy Methodology

Building activity data by member community was provided by Metro Vancouver staff. Both embodied and operating emissions are calculated for each member using the same methodology used for the regional inventory.

Transportation

Embodied and Operating Energy Methodology

Private Vehicles

Allocation to member communities is by ICBC registration data for that community and average vehicle trip length from Appendix A of the 2011 TransLink Trip Diary. For each vehicle type a weighting based on GHG emissions was derived using total regional emissions for that vehicle type and total registered vehicles. For example, for private cars 1,582,173 tCO_2e were emitted in 2015 in the Metro Vancouver region by 624,046 registered vehicles, resulting in 2.54 tCO_2e/vehicle/yr. Similarly, factors were derived for private trucks (3.70 tCO_2e/vehicle/yr), motorcycles (1.18 tCO_2e/vehicle/yr), and motor homes (3.83 tCO_2e/vehicle/yr). Total CO_2e emissions were calculated for each community. The percentage of CO_2e contributions for each community relative to the regional total was scaled by the average vehicle trip length for each community relative to the average vehicle trip length for the region. These percentages were then used to allocate embodied emissions of vehicle materials, embodied emissions of fuel and operating emissions for each community.

Challenges and Opportunities

The method for obtaining the CO_2e/vehicle/year factors could have been repeated to derive factors for CO_2, CH_4 and N_2O and then apply these to each members' vehicle count by type.

The average vehicle trip lengths from the 2011 TransLink Trip Diary are likely not relevant for motorhomes; i.e. variations in the average trip length by community will not correlate with variation in trip lengths for motorhomes since it is assumed they are primarily used for trips leading out of boundary. However, the impact of motorhomes on in-boundary emissions is very small so they were not separated from other private vehicles.

Transit - West Coast Express

Emissions were allocated based on station locations. Coquitlam, Port Coquitlam, Pit Meadows, Port Moody which have one station are allocated 16.7% and Maple Ridge which has two stations is allocated 33.3% of the region's portion of emissions for the West Coast Express.

Transit – Seabus

Emissions were allocated 70%/30% to North Vancouver and Vancouver respectively. North Vancouver's portion was then allocated again 70%/30% to North Vancouver City and North Vancouver District respectively. This results in allocations of 49% to North Vancouver City, 30% to Vancouver, and 21% to North Vancouver District.

All Other Operating Energy

All other regional operating emissions are allocated to Metro Vancouver communities by population.

Sources

TransLink. (2013). *2011 Metro Vancouver Regional Trip Diary Survey*. Retrieved from https://www.TransLink.ca/plans-and-projects/data-and-information/research-and-insights#transportation-surveys