Metro Vancouver Regional Consumption-Based Emissions Inventory

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Prepared for Metro Vancouver

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Abbreviations

BCIT	British Columbia Institute of Technology
CBEI	Consumption-Based Emissions Inventory
CHASS	Computing in Humanities and Social Sciences
CH_4	Methane
CO_2/CO_2e	Carbon dioxide / Carbon dioxide equivalent
GFA	Gross Floor Area
GHG	Greenhouse gas
HS	Harmonized System 10-digit merchandise codes by origin
LCA	Life Cycle Analysis
MV	Metro Vancouver
N_2O	Nitrous oxide
tCO_2e	Metric tonnes carbon dioxide equivalent
tCO_2e/ca	Metric tonnes carbon dioxide equivalent per capita

Definition of Terms

CO_2e	Carbon dioxide equivalent expresses the impact of each different greenhouse gas in terms of the amount of CO_2 (carbon dioxide) that would create the same amount of warming. This enables reporting of total greenhouse gas emissions in one measurement.
Ecological Footprint	An estimate of how much biologically productive land and water area an individual or population needs to produce all the resources it consumes and to absorb the waste it generates. It is measured in global hectares (gha) where a global hectare is a biologically productive hectare with globally averaged productivity for that year.
ecoCity Footprint Tool	A tool developed by Dr. Jennie Moore, with the capacity to create multiple outputs: an urban metabolism, a territorial greenhouse gas emissions inventory, a consumption-based greenhouse gas emissions inventory, as well as an ecological footprint.
Embodied Energy	Energy used in creating and delivering a material (e.g., consumable good or infrastructure), including energy used for extraction of raw materials, manufacturing and transportation of the end product.
Embodied Emissions	All other greenhouse gas emissions not captured as direct emissions in the consumption-based emissions inventory.
Food miles	The distance food travels from where it is grown or made to where it is purchased or consumed by the end user.
Operating Energy	The energy used in the function of a product, building, vehicle, etc.
Operating Emissions	The greenhouse gas emissions associated with operating energy.
Territorial inventory	Also known as a Sectoral Inventory. Metro Vancouver's Territorial inventory identifies direct emissions from all sources within the region (it does not include emissions associated with electricity, and is thus considered a 'Scope 1' inventory; a 'Scope 2' inventory would include impacts of imported electricity).
Urban Metabolism	A study of the flow of energy and materials through the urban system.

Executive Summary

Overview

This report presents a Consumption-Based Emissions Inventory (CBEI) for the Metro Vancouver region for the year 2015, to align with the Metro Vancouver Regional 2015 Territorial Inventory. It summarizes inventory results, comparing them with the region's 'territorial' greenhouse gas (GHG) inventory (page 8); highlights community level differences (page 21); provides a detailed methodology (page 3), and appendices (page 32); and identifies opportunities for next steps, including key priorities for policy intervention (page 27).

Context

A growing number of local governments are beginning to develop CBEIs, recognizing that traditional GHG emissions inventories do not fully account for the "embodied" emissions associated with "consumption" attributable to the community. That is, they miss those emissions that occurred outside the regional boundaries during the production of all the consumable goods, food, building materials, vehicles, etc., upon which the community members depend, as well as the impacts of residents and local businesses while they are travelling outside the community's borders.

CBEIs do not replace territorial inventories; they are complementary to them. It remains important to address all emissions that directly arise from activities within the region (i.e., including activity associated with exports). The CBEI highlights additional key priorities that should be addressed through policy, planning and community mobilization efforts to address the global climate change challenge and support Metro Vancouver's climate action strategy and goals. The CBEI can also help inform circular economy initiatives, goals and policies, by providing metrics that can help identify priorities for action.

Results

The CBEI for the Metro Vancouver region is 23.3 $MtCO_2e$, 58 percent higher than the traditional, territorial emissions inventory (see Figure 1).[1] This result is typical of a 'consumer' society, which imports much of its consumable goods.

[1] This result likely represents an underestimate of consumption-based emissions, due to the conservative approach employed in the inventory methodology, combined with the presence of data gaps, as articulated in the methodology section of this report.

The CBEI also highlights differences across the 23 member communities[2] (see page 21); it shows that buildings emissions correlate with building size and type, and transportation emissions correlate with the level of vehicle ownership, vehicle type, and average vehicle trip distance.

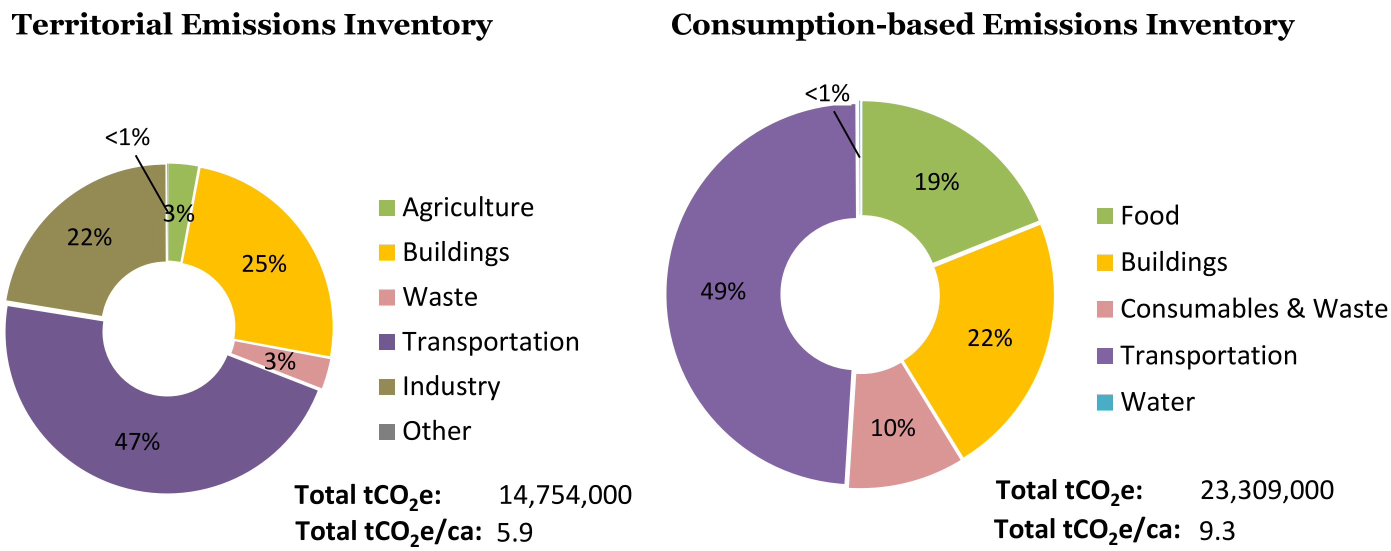

Figure 1: Comparison of the Metro Vancouver Regional Territorial GHG Emissions[3] (left) and Consumption-based GHG Emissions (right), 2015

Next Steps & Taking Action

The Metro Vancouver regional CBEI was developed using the ecoCity Footprint Tool, which employs a bottom-up (or 'component') methodology. This approach although better aligned with local government planning and policy development has greater potential for data gaps than top-down methodologies. In addition to highlighting priorities for action from a consumption-based perspective, this report identifies key data gaps, significance of the data gap and opportunities to fill priority data gaps. It is recommended that these gaps be filled over time, and targets adjusted accordingly.

To date there are limited examples of application of CBEI results, but there are a growing number of local governments leading early efforts, particularly in British Columbia, Canada. These include measures to address embodied emissions of buildings (City of Vancouver), inclusion of CBEI results in Climate Action Plans (District of Saanich), and development of policies and programs to address food waste (Metro Vancouver).

[2] Including: 21 municipalities, 1 electoral area, and 1 treaty First Nation.
[3] Source: updated 2015 Metro Vancouver Emissions Inventory, provided by Metro Vancouver staff

In taking action, key priorities indicated by the CBEI can be pursued:

- **Focus on embodied emissions of buildings**: Currently, the majority of the CBEI for buildings and transportation are associated with operating emissions, indicating the continued need for fuel switching, mode shift and efficiency. As these efforts progress, embodied emission impacts will comprise an increasing percentage of the CBEI, necessitating consideration of low carbon planning, construction and manufacturing practices, as well as continued emphasis on efficient land use that reduces the need to travel.
- **Focus on wasted food and low emission diets:** Food represents 19% of the CBEI, whereas agriculture represents only 3% of the territorial inventory. In the CBEI, most of the impacts from food are upstream (i.e., from farming); and more than half of the total is associated with animal proteins. These results indicate the need to reduce the GHG impacts of food, through changes in farming practises, reduction in wasted food, shifting to low-emission diets, and improving the efficiency of food production.
- **Focus on consumption-reduction and decarbonizing supply chains:** Similar to food production, the emission impacts of consumable goods, from a consumption-based perspective, are driven by upstream emissions. This illustrates the importance of decarbonizing supply chains, reducing the overall consumption of 'stuff' and reducing the material and energy intensity of manufacturing.

Background

This Consumption-Based Emissions Inventory (CBEI) will help inform Metro Vancouver's pursuit of becoming a carbon neutral region and support its ongoing efforts to be at the forefront of sustainability leadership. As stated in Metro Vancouver's 30-year climate action strategy - Climate 2050 – "the territorial inventory combined with the CBEI can provide a more complete picture of the region's greenhouse gas emissions and offer insights into the most effective actions to reduce global emissions". The regional CBEI is also a means of supporting the efforts of member communities, many of whom are expressing interest in understanding and acting on consumption-based emissions.

About Consumption-based Emissions

Since the late '90s, governments have typically created greenhouse gas (GHG) emissions inventories using an in-boundary or territorial approach (also referred to as a sectoral inventory). These inventories evaluate emissions from sources within a particular region, and can sometimes include emissions from out-of-region grid electricity and waste management. However, this form of inventory does not provide a complete picture of a community's impact on global climate change. It excludes some of the climate impacts associated with the goods a community consumes, because many of these goods are produced in other regions, often on other continents. It also excludes the out of boundary impacts residents and local businesses have while they are travelling outside of their community. Leading local governments are beginning to evaluate and act on these consumption-based emissions. The distinction between the territorial/sector-based inventory and the CBEI is visualized in Figure 2.

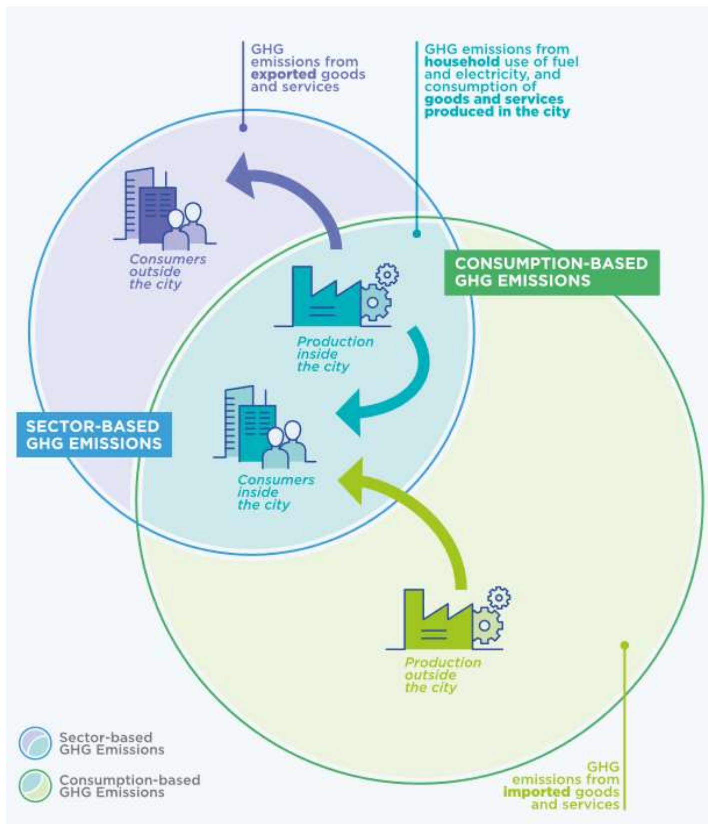

Figure 2: Comparison of Sector-based/ Territorial Emissions with Consumption-based Emissions[4]

[4] Source: Reproduced from: C40 Cities (March 2018). *Consumption-based GHG Emissions of Cities*, p.4.

CBEIs include the emissions that are generated during the production, shipping, use and disposal of all goods consumed in the region, regardless of where they are produced, as well as the impacts of residents and local businesses while they are travelling outside the community's borders. The CBEI is complementary to the territorial inventory. It is important to track local emissions through the territorial inventory, for example to monitor the emission intensity of local industrial and commercial activity, but consideration of consumption-based emissions facilitates an understanding of global emissions resulting from local consumption habits. The CBEI will thus help encourage strategies that maximize global, not just local emission reductions. It also provides the opportunity to engage stakeholders in understanding the broader emission impacts of their lifestyles and behaviours and can thus more effectively mobilize emission reduction actions.

Inventory Scope and Methodology

Scope

This report presents a 2015 Consumption-based Emissions Inventory (CBEI), to align with Metro Vancouver's 2015 regional territorial emissions inventory. In addition to presenting a regional consumption-based emissions inventory, this report also conveys municipal level differences.

The inventory is presented in CO_2e (carbon dioxide equivalent), and where available, a detailed breakdown by sub-gases CO_2, CH_4, N_2O (carbon dioxide, methane and nitrous oxide) has been included in the detailed datasets provided to Metro Vancouver.

Methodology

The CBEI presented in this report was generated using the ecoCity Footprint Tool (the Tool). The Tool, developed by Dr. Jennie Moore, has the capacity to create multiple outputs: a territorial greenhouse gas emissions inventory, a CBEI, an ecological footprint[5] and with additional development, an urban metabolism.[6] For the purposes of this analysis, only a CBEI was generated.

The CBEI, like a typical GHG emissions inventory aligns with the spheres, or categories, of municipal planning – buildings, transportation, waste and water management; but for the CBEI, a fifth category – food – is also included (see Figure 3).

Using the ecoCity Footprint Tool, data is collected on materials, embodied energy, and operating energy[7] for each of these categories; and they are evaluated by sector – residential, institutional, commercial, and industrial.

Background: The ecoCity Footprint Tool

A prototype of the ecoCity Footprint Tool was initially developed using the Metro Vancouver region as a case study, and subsequently adapted and applied to the City of Vancouver in 2009. The outputs from the Tool informed the strategies, actions, and monitoring methods for the City of Vancouver's "Greenest City 2020 Action Plan". With funding from the Urban Sustainability Directors Network and the Real Estate Foundation of BC, the Tool has been further refined and used to generate CBEIs for North Vancouver, Surrey and seven other BC communities. To facilitate easy access to the Tool an online platform is now being created.

[5] An ecological footprint estimates how much biologically productive land and water area an individual or population needs to produce all the resources it consumes and to absorb the waste it generates. It is measured in global hectares (gha) where a global hectare is a biologically productive hectare with globally averaged productivity for that year.
[6] An urban metabolism traces the flows of energy and materials through an urban system.
[7] Built area data is also collected and used to calculate the ecological footprint, but not used in the GHG inventories.

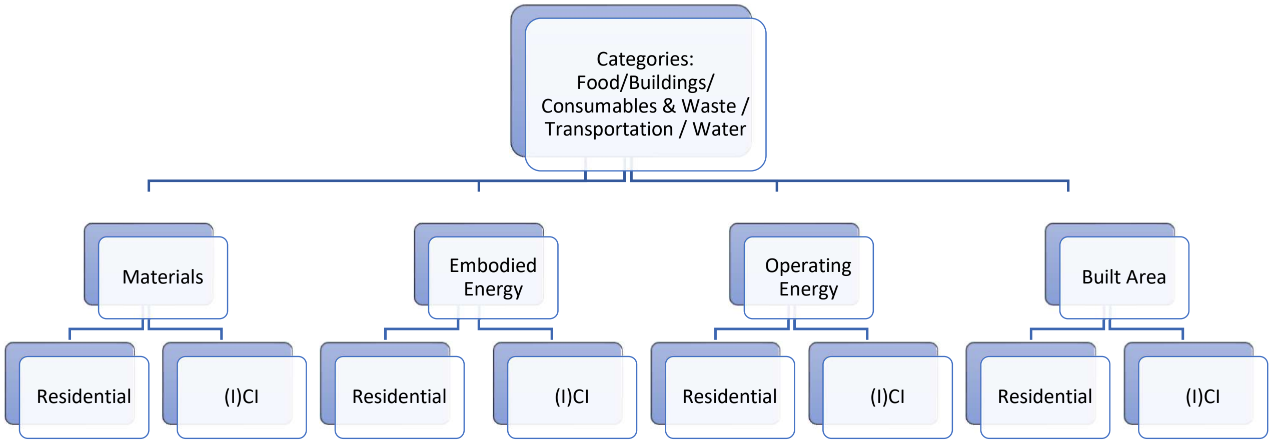

Figure 3: Schematic of Data Inputs for the ecoCity Footprint Tool[8]

C40 Cities and other organizations conducting CBEIs typically use a **'compound method'**, which is a **top-down** approach that uses national and/or econometric data. In contrast, the methodology employed in the ecoCity Footprint Tool is based on a **bottom-up 'component method'**, which emphasizes the use of community-based data, and aligns with traditional spheres of planning at the local government level (see Figure 3). In this way, the Tool facilitates the use of community- and regional-scale data sources, but in cases where local data is not available, assumptions or proxies are utilized.

Disaggregation by Member Community[9]

In addition to a region-wide inventory, this report presents disaggregated results by member community. This serves to highlight differences in consumption-based emission impacts across the region.

Where available, activity data across each of the member communities was utilized to generate the inventory, and in cases where localized data was not available, regional totals were allocated based on the population of each community. A detailed overview of the allocation methodology is provided in the appendices (see page 32).

Key Assumptions and Limitations

There are two distinct methods for developing CBEIs – the compound and component methods (see Figure 4). As noted above, the CBEI for the Metro Vancouver region has been generated using the component (bottom-up) method. The key drawback to the component approach is that there can be data gaps and thus under-estimates of GHG emissions compared to the inventories

[8] (I)CI refers to light industrial, commercial and institutional sectors.
[9] For the purposes of this report, 'member community' includes 21 municipalities, 1 electoral area, and 1 treaty First Nation.

generated with a compound (top-down) methodology. However, use of consumption (activity) data[10], collected through an urban metabolism study,[11] provides advantages for local government planning purposes as it can directly link policy intervention to emissions at the local government scale.

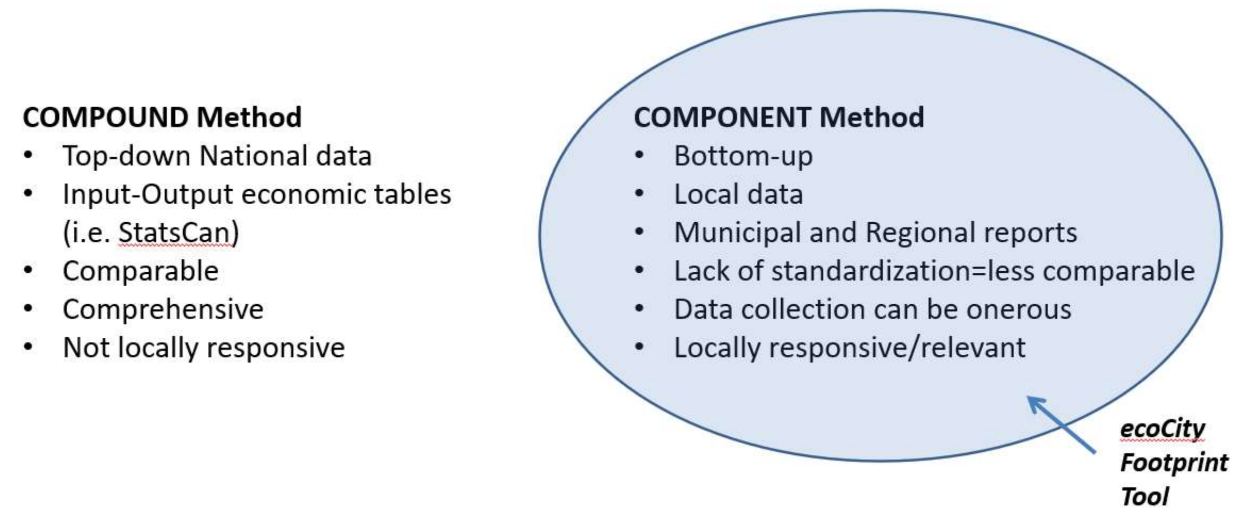

Figure 4: Two methods for calculating the CBEI

An overview of the data inputs required to generate the CBEI, and key assumptions and limitations are presented in Table 1, below. A detailed overview of the methodology, data sources, and challenges and opportunities are presented in Appendix B.

[10] Such as consumption data from utilities and waste and recycling tonnages.
[11] The urban metabolism (UM) traces flows of energy and materials through a community and yields data to inform the GHG inventory.

Table 1: Key Assumptions and Limitations

Category	Details	Key Assumptions & Limitations
Food	Embodied energy associated with food production (energy used for farming) and operating energy to transport imported food	Food consumption and 'food miles' statistics were not available at the local level, therefore, national averages were used as a proxy. Local data could potentially be collected in the future via the Lighter Footprint App (currently under development), or a regional food survey, or working directly with food wholesalers and distributors. Food miles statistics were only available for food imported to Canada (data on food transport within Canada is not available). A number of assumptions relating to food distance travelled and transport mode are summarized in Appendix B.
Buildings and Stationary Energy	Embodied energy and operating energy associated with residential, commercial, and institutional buildings	Factors for embodied emissions of materials for buildings are derived from a limited local dataset. There are also few national and international studies that are available for comparison. Embodied emission factors associated with maintenance, renovations and furniture over the lifespan of buildings are not included. Estimates for building lifespan are based on 2009 regional data (40 years for wood frame and 75 years for concrete/steel frame). Embodied emissions impacts are amortized over the lifespan of the building.
Consumables and Waste	Direct emissions from waste facilities (i.e., landfilled, incinerated, composted, wastewater) Embodied energy of disposed and recycled materials (i.e., consumable goods) Operating energy used at waste management facilities and hauling waste Embodied energy of wastewater treatment system	The total quantity of goods consumed in a given year is derived from waste and recycling numbers, assuming the majority of materials consumed are disposed within the year and that there is a steady flow of durable goods disposed every year equivalent to the new durable goods supply entering the region. Composition data for waste and recyclables are based on Metro Vancouver regional totals. The Tool does not include Life cycle analysis (LCA) values for all recycled material types (only recycled paper, plastic, glass, and metal are included).

Category	Details	Key Assumptions & Limitations
Transportation	Embodied energy associated with private and commercial vehicles, fuels and roads Operating energy associated with transportation (fuel use for private and commercial vehicles; transit; aviation; marine vessels and off-road vehicles/equipment)	Roadway materials are estimated by extrapolating from a City of Surrey study, which was the best available data set (estimated lifespan: roads 50 years; cars 15 years). Private and commercial vehicle emissions were only available for in-boundary travel. Air travel estimates are conservative as they do not include second-leg flights. Estimates are based on assumptions from YVR regarding percentage of travelers that are from the MV region. Estimates for smaller airports in the region are also included. BC Ferries data was limited to total fuel consumption. Due to the lack of passenger origin-destination information, total fuel consumption was allocated based on the Metro Vancouver region's proportion of BC's population. This method does not account for the significant use of Ferries by tourists or the regional differences in ferry usage. Embodied energy of materials for rail, ferries, aircraft, off road vehicles and equipment were not included in the inventory.
Water	Embodied energy of materials associated with water infrastructure Operating energy used in treating and conveying water	Embodied energy of concrete dams, pipe network and roads were included. The long lifespan of this infrastructure results in a small annual emissions contribution despite the large volume of materials used (estimated lifespan: concrete and concrete lined pipes 100 years; steel, ductile iron, and cast-iron pipe 50 years).

Inventory Results

This section details the Metro Vancouver regional CBEI results, summarizing total emissions, and emissions by category. It also compares the CBEI results with the region's existing territorial emissions inventory and explores municipal level differences.

Comparison of Inventories - CBEI vs Territorial

The 2015 CBEI for the region was **23.3 MT CO_2e**, while territorial emissions were estimated at **14.8 MT CO_2e** (see Figure 5).

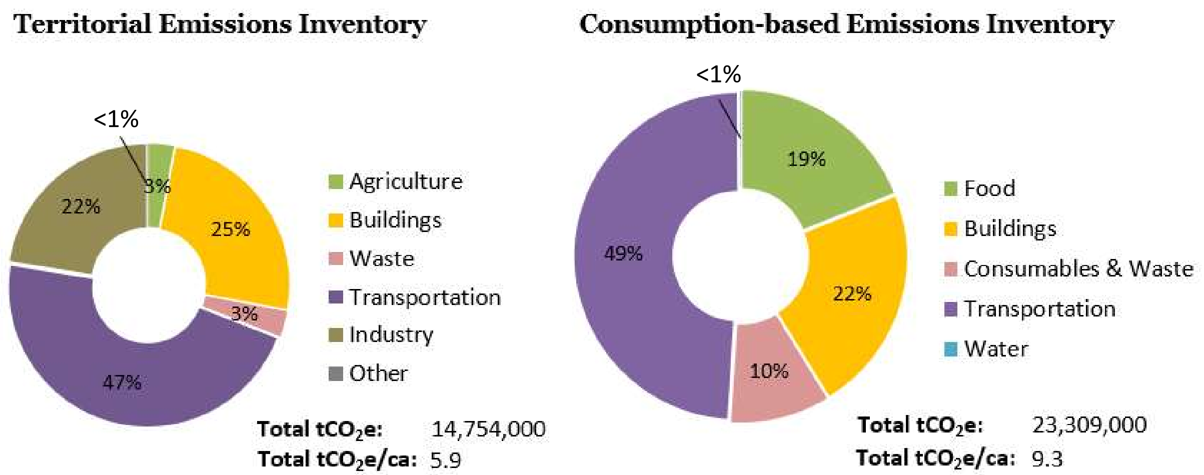

Figure 5: Comparison of the Metro Vancouver Region's Territorial GHG Emissions[12] (left) and Consumption-based GHG Emissions (right), 2015

Impacts of a Shifting Economy

The Metro Vancouver regional CBEI is larger than its territorial inventory – as is typical of a 'consumer' society that has significant out of boundary impacts (e.g., imports and travel). In contrast, there are many 'producer' communities around the world whose economies are more dependent on manufacturing and exports, and for these communities their CBEI may be much smaller than their territorial inventory.

A territorial approach obscures the impacts of changes occurring in the global marketplace, e.g., reduced in-boundary production that has been supplanted by increased out of boundary production to support local needs. In these cases, a territorial inventory would decrease even with increased local consumption. A CBEI, however, would not be affected by this change in the economy – emissions are included regardless of where they occur.

[12] Source: updated 2015 Metro Vancouver Emissions Inventory, provided by Metro Vancouver staff.

The overall contribution of buildings and transportation to CBEI and territorial emissions are similar in terms of percentages (representing approximately one-quarter of the total for buildings and one-half for transportation for both types of inventories). However, food and consumables and waste make up a much larger percentage in the CBEI compared to agriculture and waste in the territorial inventory.

The difference between the two inventory results can be primarily attributed to the upstream GHG impacts of food production and the embodied emissions associated with the built environment, transportation and consumables, which are included in the CBEI. Consumption-based emissions are significantly higher than territorial emissions even though there are substantial industrial emissions included in the territorial inventory that are excluded from the CBEI, because they are associated with exported goods. See Table 2 and Appendix A for a detailed overview of what data sets are included in each inventory type.

The details of what emissions are captured in the territorial inventory versus the CBEI are summarized in Table 2, with additional explanation provided in Appendix A.

Table 2: Comparison of Emissions Captured in the Metro Vancouver Region's 2015 Territorial GHG Inventory vs Consumption-based GHG Inventory

	Territorial GHG Inventory (In-boundary)	Consumption-based GHG Inventory (In-boundary & out-of-boundary (global))
Agriculture/ Food	- food and non-food farming - in-boundary transport	- food farming only - more sources from farming - all food (and associated food waste) consumed in-boundary - imported (into Canada) food transport - in-boundary transport - fuel (embodied)
Buildings	- operating (including wood - CH_4, N_2O only) - in-boundary fugitive	- operating (not including wood) - initial construction material embodied - fuel (embodied -includes fugitive)
Waste/ Consumables and Waste	- all in-boundary active and closed landfills - incineration - wastewater	- all active landfills - incineration - composting - wastewater - disposed and recycled materials embodied (consumables) - wastewater pipe network embodied - facilities operating - fuel (embodied)
Transportation	- private and commercial vehicles, aircraft, rail, marine vessels and non-road (including shipping) in-boundary operating	- private and commercial vehicles and non-road in-boundary operating - aircraft, rail and marine vessels full trip operating - most shipping captured in other categories - material embodied (private and commercial vehicles) - fuel (embodied)
Water		- facilities operating - material embodied (dams, roads and pipes) - fuel (embodied)
Industry	- in-boundary industry (operating and processing)	- global industry (operating and processing) attributable to regional consumption – captured in other categories
Other	- land and structural fires	

CBEI of Food

As Figure 6 shows, the majority of emissions associated with food are due to production activities (97%); while only 3% of food emissions are due to the transport of food (i.e., food miles).[13] Thus, it is really production energy that drives the impact of GHG emissions associated with food. This is not to say that shifting to local food production is not important – but rather it highlights the need to focus on the energy and emissions intensity of food production.

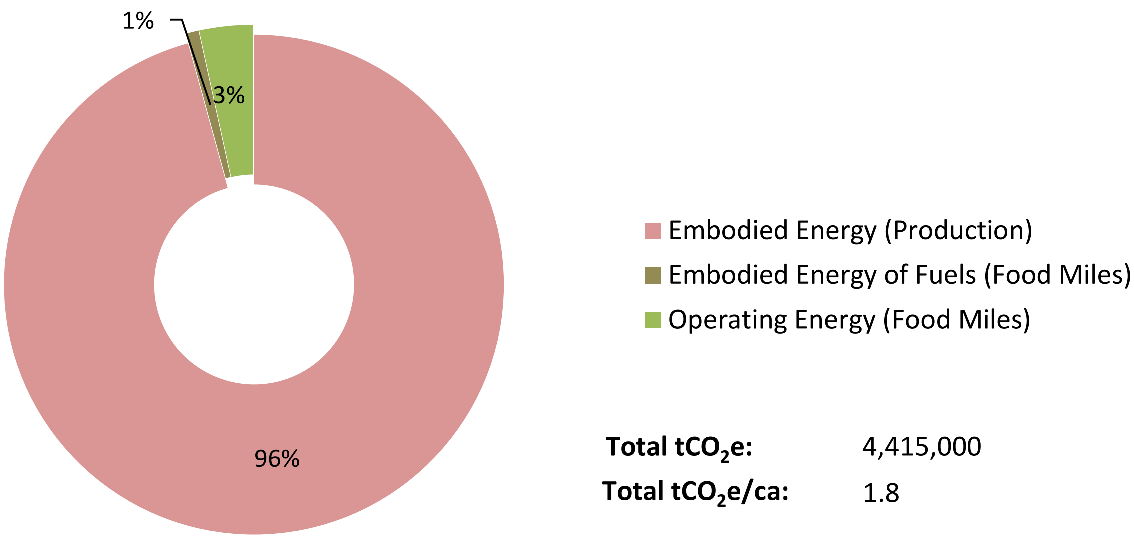

Figure 6: CBEI of Food for the Metro Vancouver Region, 2015

However, the relative impact of food miles varies significantly by food type. The relative impact of food miles is lowest for foods that have the highest emissions intensity associated with production (e.g., meat and cheese), and highest for foods with lower production impacts (e.g., fruits and vegetables).[14] This suggests that with a shift to lower impact diets (e.g., vegetarian and vegan) food miles would become more significant contribution to the CBEI for food.

The relative impact of food miles will also shift over time with advances in lower impact farming that will reduce emissions from production. Experimental farms are developing practices to reduce emissions, such as through soil management (currently by far the largest contributor to farm emissions) as well as measures to capture emissions from manure and enteric fermentation which could then be utilized and/or sequestered.

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[13] Emissions associated with composting food waste are included within the consumables and waste category. These emissions are equivalent to approximately 71,000 tCO2e, which would increase the GHG impacts of food by about 2%.

[14] The relative impact of food miles compared to production energy is 1% for meat and dairy but 35% for fruit and vegetables (as shown in detailed results, not presented in this report).

To inform policy and planning decisions it is important to consider the varying contributions of each of the food types to the overall food emissions. Figure 7 shows that, 60% of the CBEI for food are attributed to animal proteins – particularly meat, and dairy (and within the dairy category, the predominant driver is cheese due to the energy intensity of cheese production).

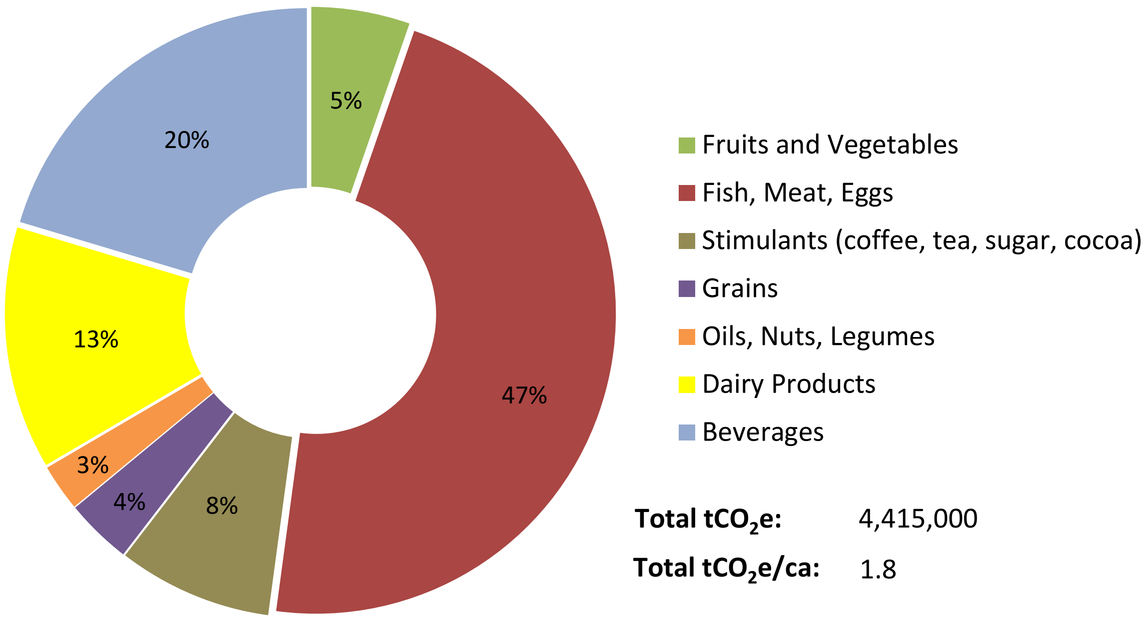

Figure 7: CBEI of Food by Type for the Metro Vancouver Region, 2015

CBEI of Buildings

The impacts of buildings are dominated by operating energy, as shown in Figure 8. However, as energy efficiency improves and fuel switching continues, the significance of embodied emissions will continue to increase. The small contribution of commercial buildings to embodied emissions is in part because these building types have longer life spans on average than residential buildings and impacts are amortized over their lifespan (estimated at 75 years for commercial buildings and 40 years for residential buildings). One shortcoming of this amortized approach to calculating emissions is that it obscures the opportunity costs of building with concrete and steel over timber and other low carbon materials. With current practices, steel and concrete will yield significant near-term emissions associated with production of materials and construction. Given the current climate emergency it will be important to balance immediate and long-term emissions impacts of building choices. A particular emphasis should be placed on extending the lifespan of buildings and adopting circular building practices which minimize raw resource extraction and waste disposal. The ecoCity Footprint Tool uses the Athena Impact Estimator[15] to generate embodied emissions estimates. The Athena tool can also be used by local governments to evaluate embodied emissions impacts of projects on a building-by-building basis.

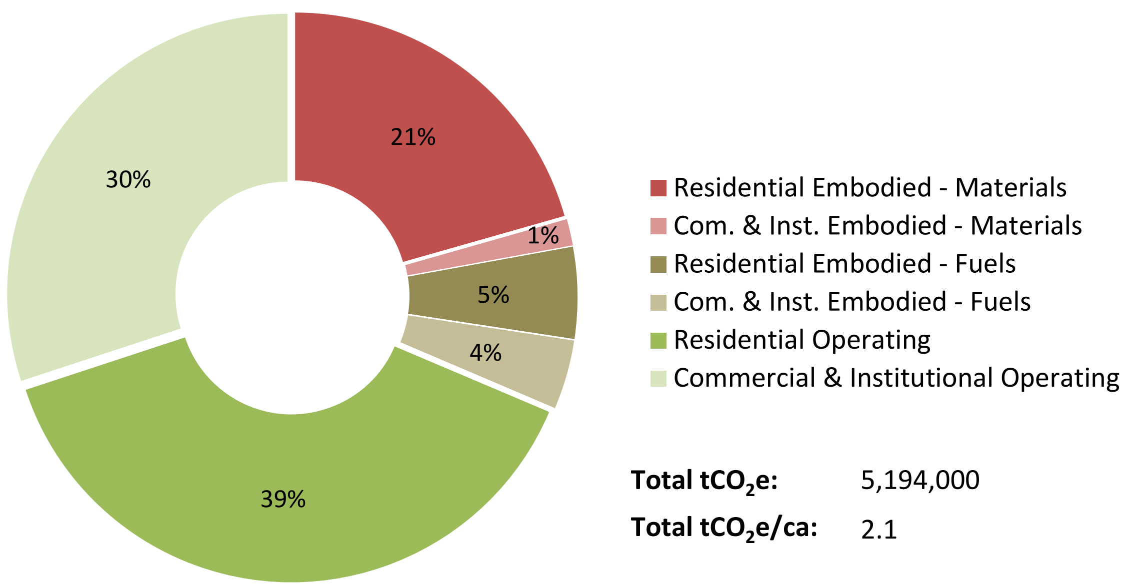

Figure 8: CBEI of Buildings for the Metro Vancouver Region, 2015

[15] See: http://www.athenasmi.org/our-software-data/impact-estimator/

As shown in Figure 9, the majority of consumption-based emissions from buildings are attributable to the residential sector (64%), with the remaining attributed to the commercial sector.

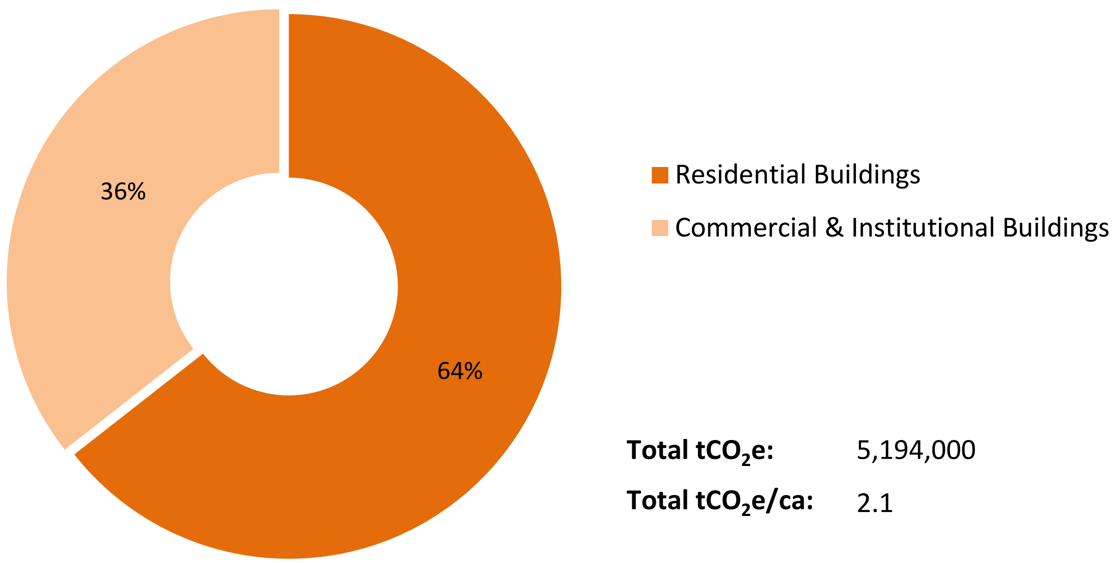

Figure 9: CBEI of Buildings by Type for the Metro Vancouver Region, 2015

CBEI of Consumables and Waste

As shown in Figure 10, embodied emissions are the dominant driver of the consumables and liquid and solid waste emissions at 81% of the total for this category (including 69% of solid waste and 12% of liquid waste). Less than 20% of the impact in this category is due to emissions directly resulting from disposal of the materials at the end of their life (see Figure 10 – Materials Disposed).

Government efforts around waste management have grown steadily over the past few decades and great strides have been made in recycling and composting. But embodied emissions analyses suggest the best tactic to yield dramatic GHG emission reductions is to minimize overall consumption of new material inputs and to decarbonize product supply chains, including through circular economy and extended producer responsibility strategies.

The results shown in Figure 10 are shown again in Figure 11 and Figure 12 below. Figure 11 includes all emissions associated with waste disposal (materials disposed, embodied energy of fuels, and operating energy) and Figure 12 includes the embodied energy of materials disposed and recycled (i.e., consumables) broken down by material type.

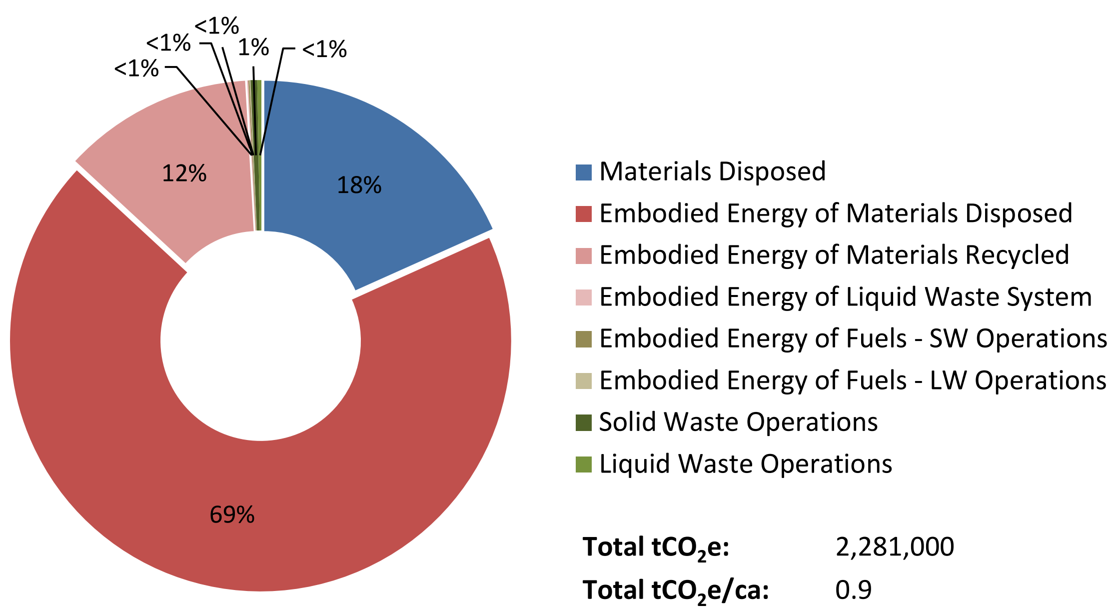

Figure 10: CBEI of Consumables and Waste for the Metro Vancouver Region, 2015

Figure 11 shows that the sectoral contributions to the waste only portion of the CBEI are roughly equally split between residential and commercial sectors at 55% and 42%, respectively, with the remainder attributable to solid and liquid waste operations.

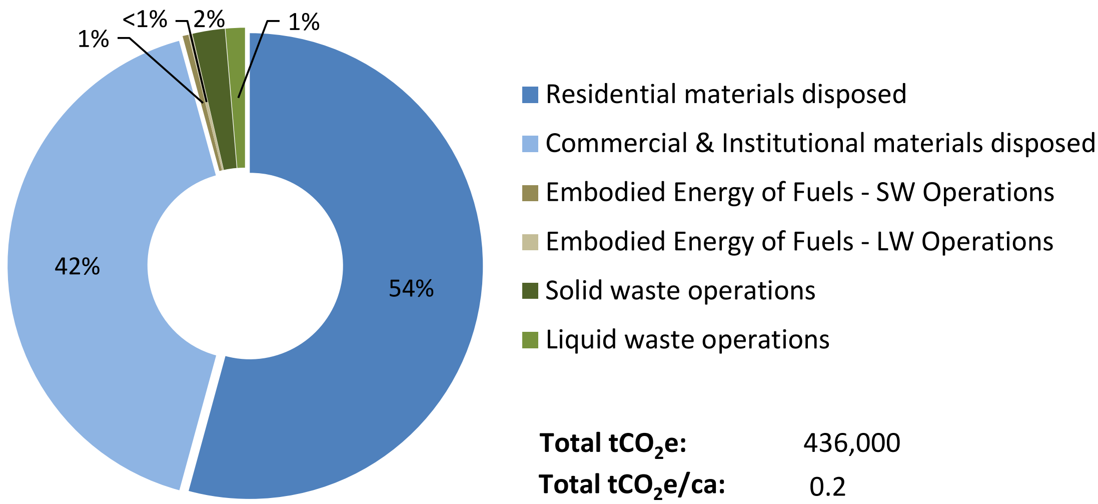

Figure 11: CBEI of Waste for the Metro Vancouver Region, 2015

Figure 12 illustrates which materials streams have the greatest impact on the CBEI, and thus which should be prioritized for reduction. The single largest contributor to the consumables portion of the CBEI is plastics (30%) - due to its high carbon intensity - followed by non-compostable organics[16],[17](16%), paper (13%) and household hygiene (12%). Appendix C contains a detailed breakdown of GHG impacts by type (that is, by type of plastic, paper, etc.).

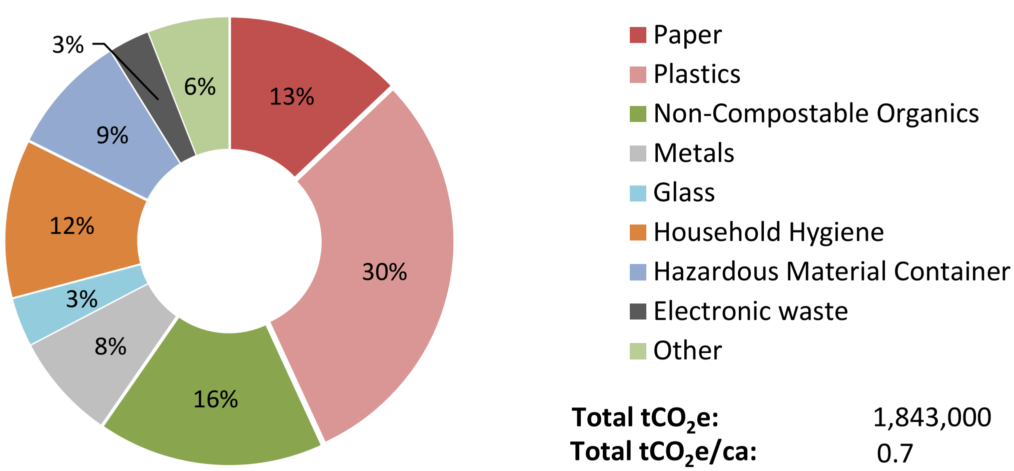

Figure 12: CBEI of Consumables by Material Type for the Metro Vancouver Region, 2015

[16] 'Non-compostable organics' here includes natural fiber textiles, rubber, and non-demolition wood waste.
[17] Textiles make up approximately 70% of the impact of the non-compostable organics category.

CBEI of Transportation

Operating emissions are the largest contributor to the transportation CBEI, representing 66% of these emissions (see Figure 13). If the embodied emissions of fuels are included, the impacts of fuels make up 82% of the category. However, as the transportation fleet continues to electrify, and if vehicle numbers increase, the embodied emissions of materials will become increasingly significant.

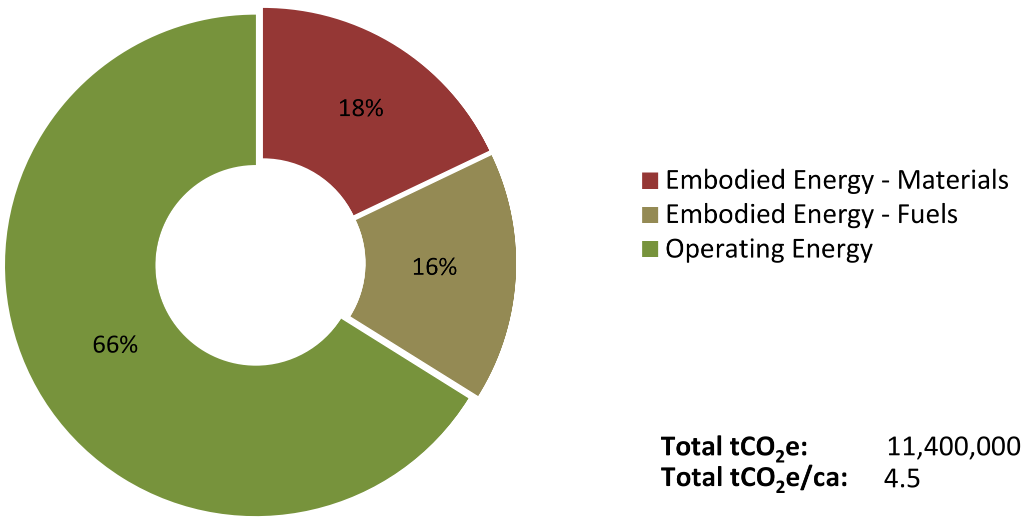

Figure 13: CBEI of Transportation for the Metro Vancouver Region, 2015

Figure 14 shows the embodied emissions of materials and fuels (from Figure 13) in greater detail. Private vehicles make up the majority of the embodied emissions at 61% of the total embodied emissions.[18] The embodied emissions of fuels are known to be underestimated. Emission factors used for the embodied emissions of fuels are global averages while it is known the emissions from extraction and processing of oil sands and fracked natural gas, from which BC's fuels are derived, are much higher than the global average.

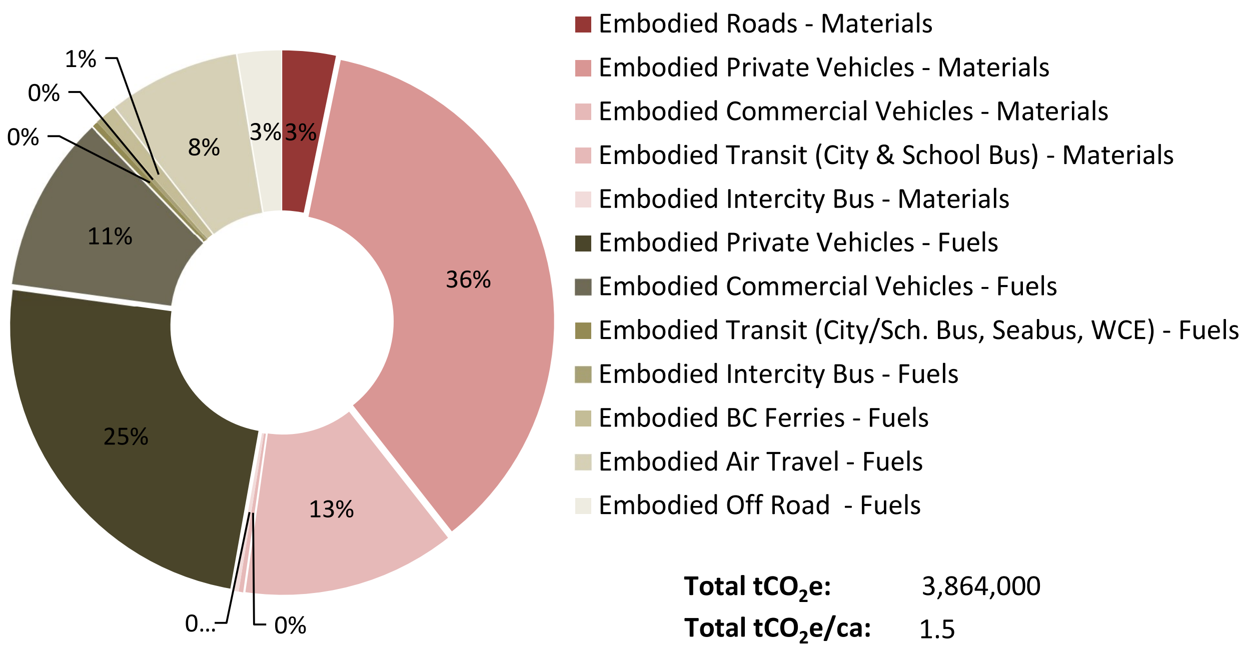

Figure 14: CBEI of Transportation (Embodied Emissions) for the Metro Vancouver Region, 2015

[18] Note that embodied emissions of materials associated with West Coast Express commuter rail, marine, aircraft, or off-road vehicles and equipment are not included in this inventory (a data gap).

Combining the embodied and operating energy of private vehicles, the total impact of private vehicles is 53% of the transportation CBEI (see Figure 15). The next most significant categories within the transportation CBEI are the emissions associated with commercial vehicles (22%), and air travel (16%). This is despite the fact that the emissions of all three of these categories are under-estimated in this inventory, as private and commercial vehicles only include in-boundary emissions, and air travel only includes the first leg of flights for Vancouver International airport and comprehensive data sets for other small airports in the region were not available.

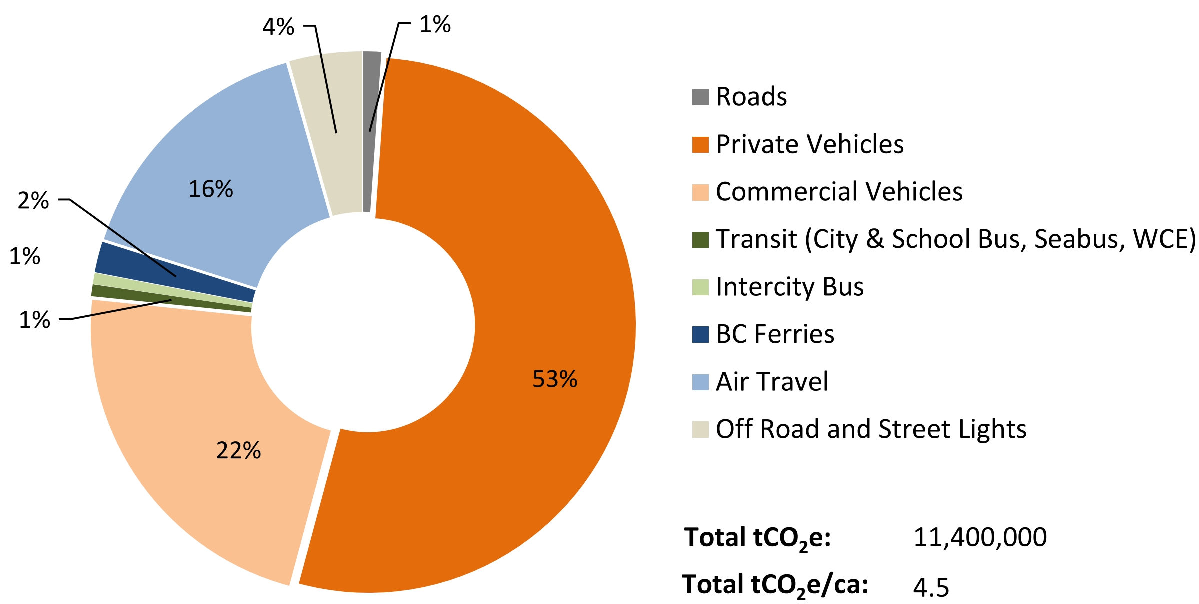

Figure 15: CBEI of Transportation, by Type for the Metro Vancouver Region, 2015

CBEI of Water

The CBEI for water reveals that embodied emissions (88%) dramatically overshadows operating energy (12%) - see Figure 16. However, the overall contribution of emissions from water supply and treatment to the region-wide CBEI is relatively insignificant (less than 0.1%). This is in part due to a predominantly gravity fed water distribution system, and the amortization of water supply infrastructure over its long lifespan (approximately 100 years).

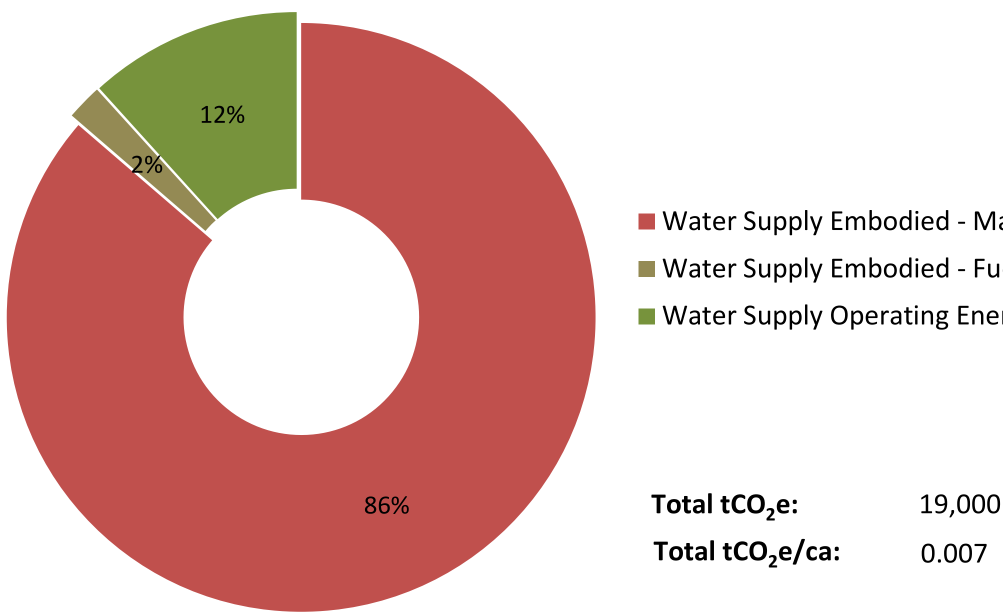

Figure 16: CBEI of Water, by Type for the Metro Vancouver Region, 2015

Inventory Results by Community

The following presents community level emissions for the CBEI across the 21 Metro Vancouver municipalities, 1 electoral area, and 1 treaty First Nation. For food, consumables and waste, and water, estimates are generated by allocating emissions by population, and thus are equivalent across the region on a per capita basis. For buildings and a portion of transportation emissions, local activity data was available and thus estimates for these categories of consumption are locally-specific and are discussed in greater detail below.

CBEI of Buildings by Community

As shown in Figure 17 there is significant variation in the buildings CBEI by community, with the highest impact being in West Vancouver, which has per capita emissions 3.8 times higher than that of the lowest emitter, Bowen Island.

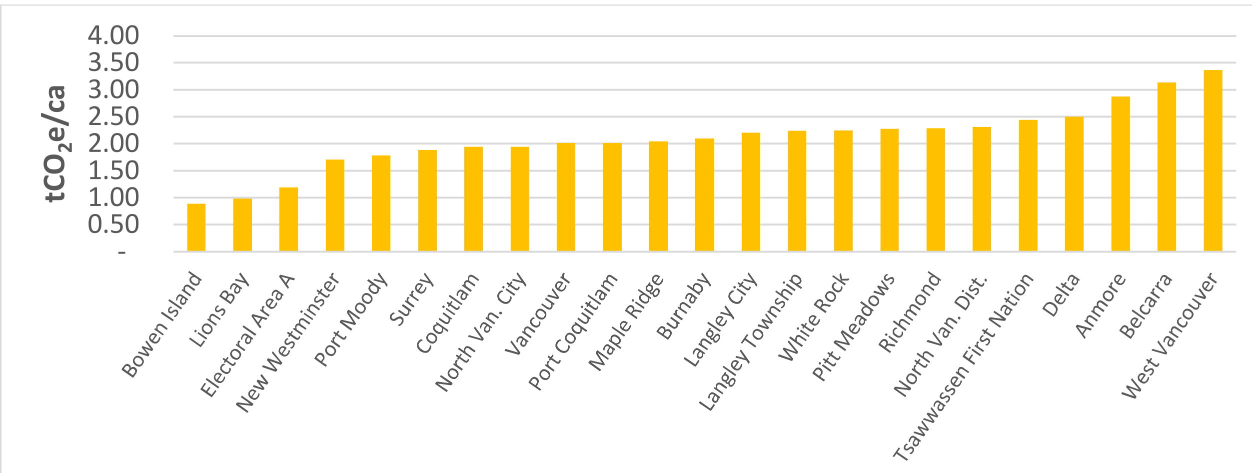

Figure 17: CBEI of Buildings per Capita by Community, 2015

Most of the variation in buildings' emissions can be explained by analyzing housing type and the level of commercial and institutional activity in each community (shown in Figure 18, Figure 19, and Figure 20, below).

Reviewing Figure 18 and Figure 19 together shows communities that do not have residential apartments in their building stock (e.g., Anmore and Belcarra) have higher amounts of lower density housing (measured in per capita gross floor area (GFA)), as would be expected. This results in both higher embodied and operating emissions per capita, assuming there is a consistent mix of fuels used for heating in the region.

These two charts also show trends in relative housing size and occupancy – for example, the residential apartment GFA for West Vancouver shown in Figure 19 is close to the regional average of 128 sqft/ca but the West Vancouver residential (non-apartment) GFA shown in Figure 18 is well above the regional average of 636 sqft/ca. This suggests that the housing is relatively large and/or there are fewer people per household. Both factors contribute to higher embodied and operating emissions per capita for West Vancouver.

Per capita commercial and institutional fossil fuel consumption for each member community is summarized in Figure 20. For those communities with the highest CBEI for buildings (Delta, Anmore, Belcarra and West Vancouver, shown in Figure 17), only West Vancouver and Delta have significant commercial and institutional emissions. This means Anmore and Belcarra's relatively high per capita emissions can be attributed to their residential housing stock (i.e., a higher proportion of larger single family homes) whereas, Delta and West Vancouver's relatively high emissions are attributed to both their residential housing stock and commercial and institutional activity.

Of note, Bowen Island and Lions Bay housing stock does not correlate with the buildings CBEI. This is likely due to a higher percentage of homes in these communities being heated with wood (wood burning is not captured in the CBEI[19]) which could result in significantly lower reported emissions.

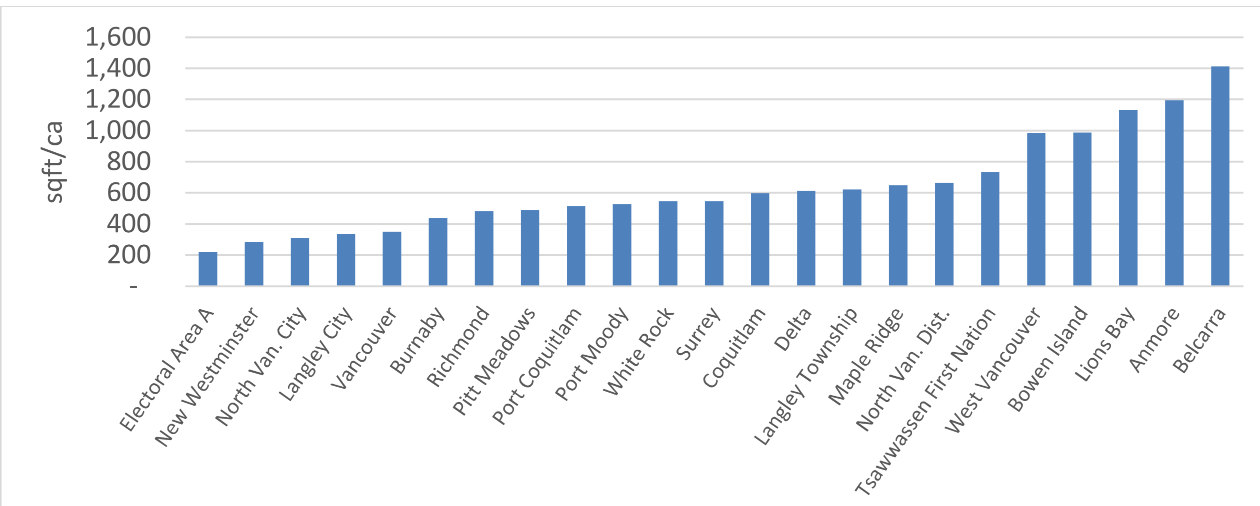

Figure 18: Residential (not including Apartments) Gross Floor Area per Capita by Community, 2015

[19] Burning wood for heating is not included in the CBEI as it is considered biogenic in the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories.

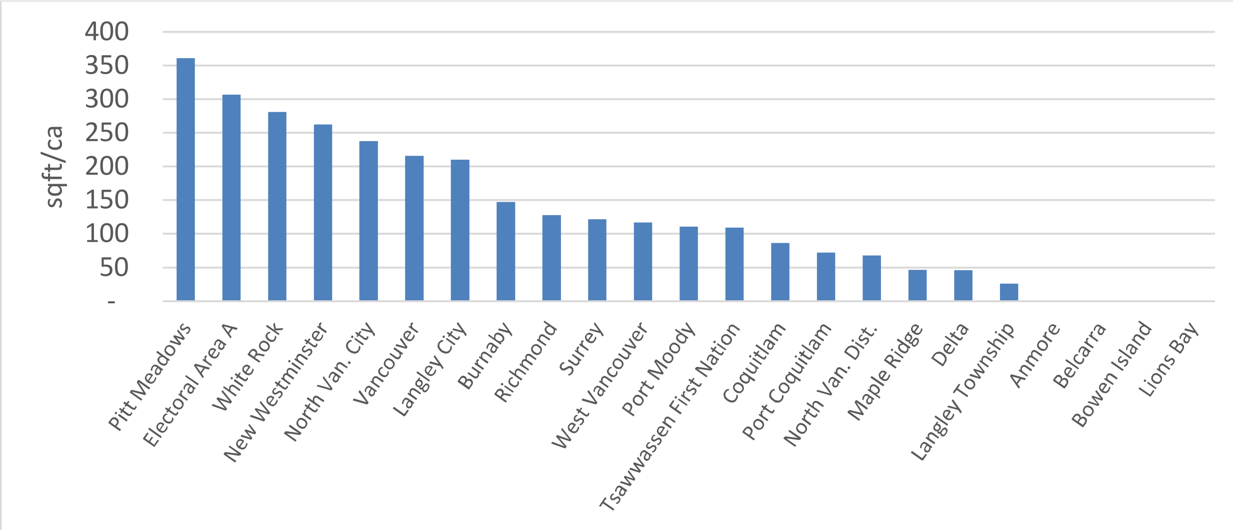

Figure 19: Residential Apartment Gross Floor Area per Capita by Community, 2015

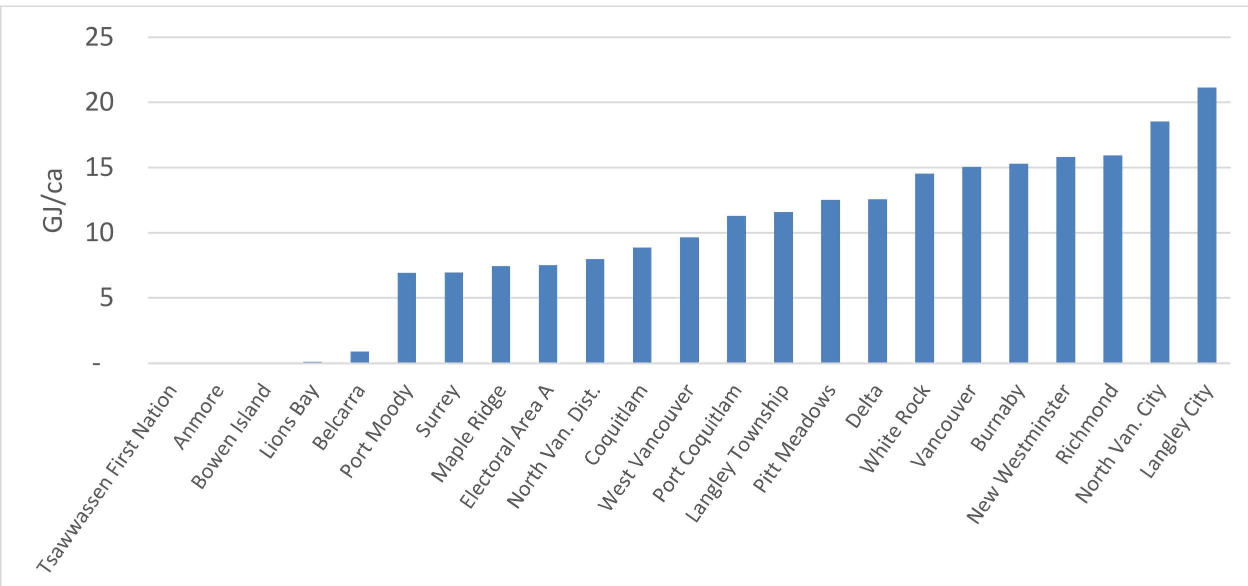

Figure 20:Commercial and Institutional Fossil Fuel Consumption per Capita by Community, 2015

CBEI of Transportation by Community

There is less variation in the CBEI for transportation by community than there is for buildings. The highest per capita contributor to the CBEI - Lions Bay - has 2.8 times higher per capita emissions than the lowest - Electoral Area A (primarily UBC and the Endowment Lands).

The transportation CBEI includes emissions associated with private vehicles, the West Coast Express, and the Seabus at the community level. The remaining emissions in the CBEI for transportation are allocated based on population, such that each community has the same per capita emissions for: commercial vehicles, bus travel, BC Ferries, air travel, and non-road (off-road) equipment/vehicles. The fact that there is still significant variation in the transportation CBEI between the communities illustrates the dominant impact of private vehicles on the CBEI (impacts from the West Coast Express, and the Seabus are minor). If just the private vehicle impacts on the CBEI are compared, the emissions for Lions Bay are 6.0 times higher than for Electoral Area A.

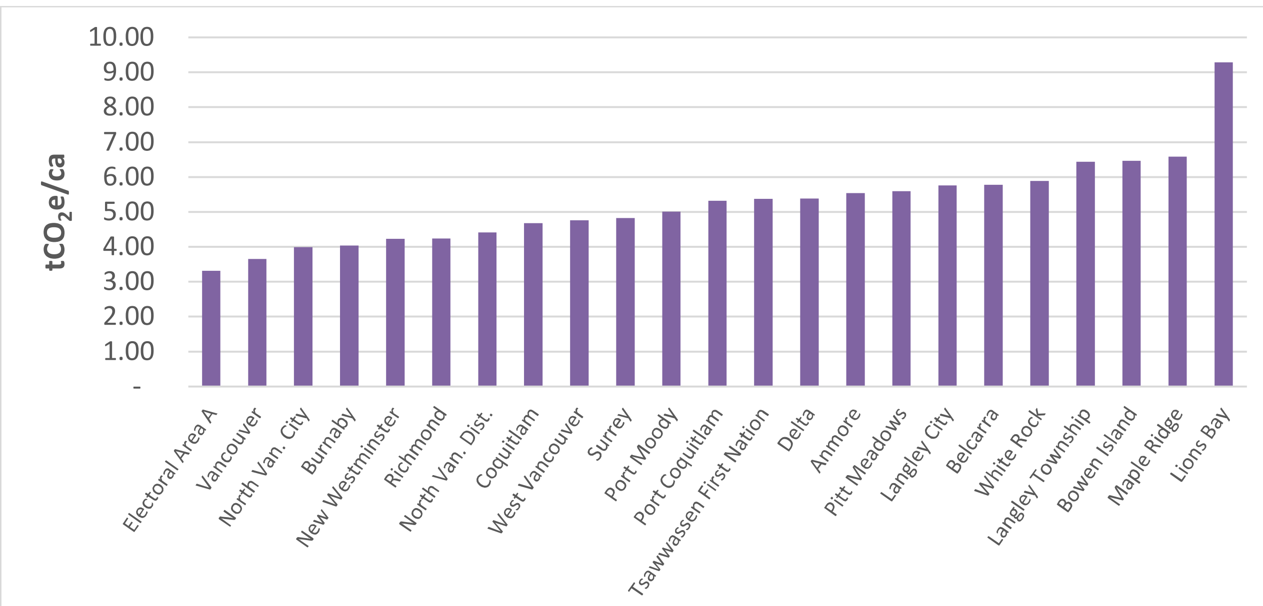

Figure 21: CBEI of Transportation per Capita by Community, 2015

The variation in private vehicle emissions can be explained by analyzing the level of vehicle ownership, the type of vehicles owned, and the average distance traveled per trip in each community (see Figure 22, Figure 23 and Figure 24, below).

As shown in Figure 22, per capita vehicle ownership (including leased vehicles) is highest in Lions Bay, at 2.4 times the ownership in Electoral Area A, which has the lowest level. Lower ownership results in lower embodied emissions and typically lower operating emissions, as people are choosing other lower emission modes of transport. Trends for the most part, are as would be expected with higher density urban centres having lower ownership levels.

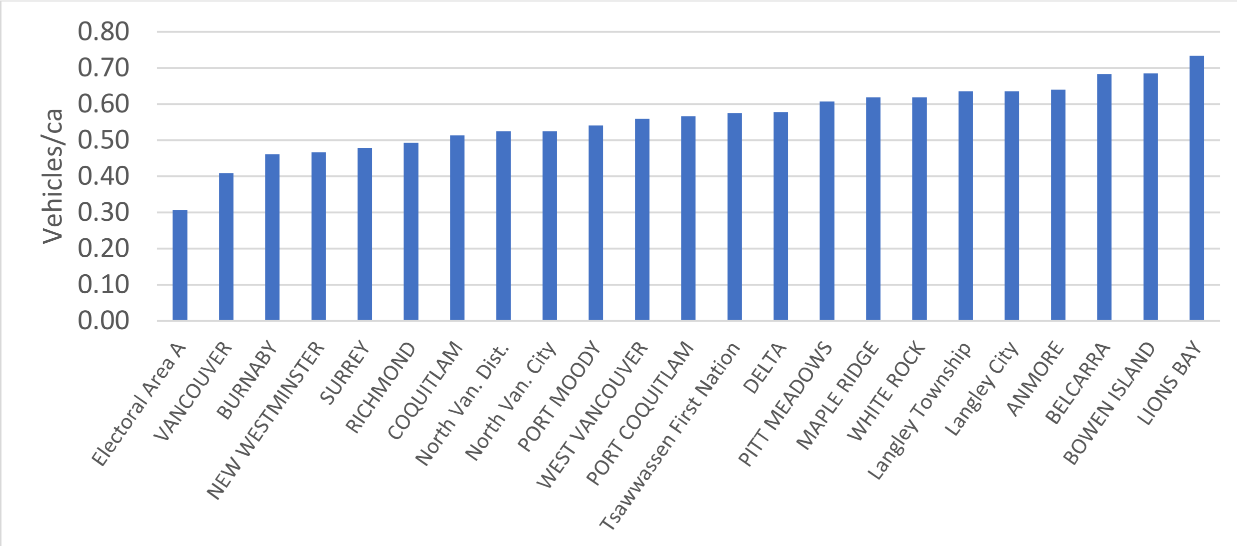

Figure 22: Private Vehicle Ownership (including leased vehicles) per Capita by Community, 2015

Table 3 shows the average annual in-boundary emissions by vehicle type for the Metro Vancouver region. Emissions from trucks, vans, and SUVs are 1.5 times higher per vehicle, on average than are emissions from cars. Given that cars and trucks (including vans and SUVs) make up the majority of private vehicles, the ratio of truck versus car ownership in each community will impact the transportation CBEI.

Table 3: Average Annual In-boundary GHG Operating Emissions by Vehicle Type, 2015

	tCO_2e/Vehicle
Private Car	2.5
Private Trucks, Vans & SUVs	3.7
Motorcycle	1.2
Motorhome	3.8

Figure 23 shows Bowen Island has the highest level of truck ownership at 57% and Vancouver is the lowest at 42%. For the most part the results are as would be expected, with higher density urban centres having a lower level of truck ownership. However, a few communities do not follow this trend such as Electoral Area A (UBC) which has a relatively high percentage.

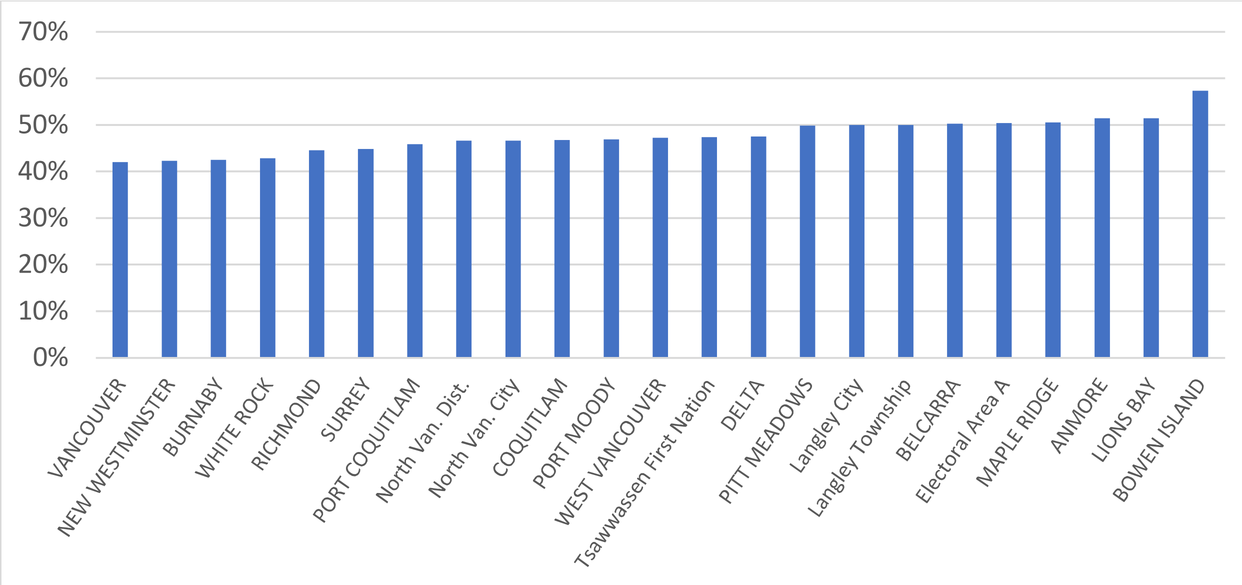

Figure 23: Percentage of Private Light Truck and SUV Ownership by Community, 2015

Figure 24 shows the variation in average vehicle trip length[20] for each community with the longest being Lions Bay, which is 2.7 times higher than the lowest (City of North Vancouver). Analyzing Figure 22, Figure 23, and Figure 24, it is clear why Lions Bay has the highest transportation CBEI, the municipality has a high level of vehicle ownership, a high percentage of vehicles owned are trucks, and the highest average vehicle trip distance.

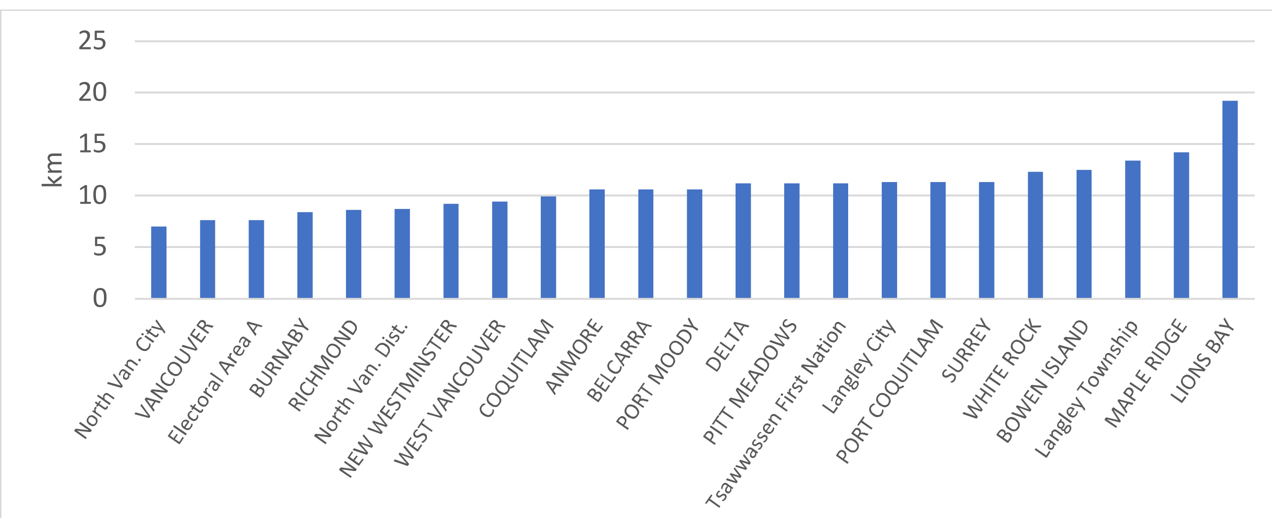

Figure 24: Average Vehicle Trip Distance by Community, 2015

[20] Average vehicle trip length for each community is based on trips by residents of that community within the Metro Vancouver region.

Recommendations for Next Steps

This section presents recommendations for next steps relating to:

- Opportunities to fill data gaps and improve data collection
- Inventory frequency
- Utilizing the ecoCity Footprint Tool to explore the region's urban metabolism and ecological footprint impacts
- How the CBEI results can be utilized in policy and planning

Data Gaps and Methodology Refinements

As previously mentioned, a drawback to the component approach utilized for this inventory (a bottom-up CBEI) is that there can be data gaps and thus under-estimates compared to the inventories generated with a top-down methodology. In the course of developing this inventory, and during development of the ecoCity Footprint Tool the most significant sources (and those most readily available) were prioritized for inclusion in the inventory.

The following summarizes the data gaps that could be filled in future inventories along with a high-level assessment of the priority that should be assigned to filling each data gap (**assessed as high, medium, low**). This assessment is based on: consideration of the likelihood of being able to fill the data gap, and also the magnitude of inventory results.

Data Gap or Methodology Enhancement	**Anticipated Significance**
Non-food related farming (e.g., nursery trees, plants, flowers, etc.).	Low
Expanded food emission sources: a portion of emissions associated with food are not currently included in the Tool, including domestic food transport, transport to processing facilities, transport by aircraft and train; and emissions resulting from the preparation of processed foods in the inventory is limited (beverages are included).	Potentially high
Local food consumption estimates. [This could potentially be filled through a food survey, research with wholesalers, or through use of the Lighter Footprint App which is currently under development]	Low, but would facilitate better analysis of policy interventions

Data Gap or Methodology Enhancement	**Anticipated Significance**
Emission factors for local food production: North American averages are currently utilized in the Tool.	Low, but would facilitate better analysis of policy interventions
Expanded embodied emissions of materials factors for buildings: current factors are derived from a limited local dataset with few national and international studies for comparison. [Recent interest in building embodied emissions is presenting opportunities to base these factors on a larger data pool.]	Low to Medium
Embodied emission factors associated with maintenance, renovations and furniture over the lifespan of buildings. [Factors could be included based on data from a limited number of studies.]	Medium
Expanded LCA data for recycling: currently the Tool only contains factors for recycled paper, plastic, glass, and metal.	Low, but would facilitate better analysis of policy interventions
Out-of-boundary vehicle travel: The TransLink Trip Diary survey used in this inventory only accounts for in-boundary vehicle emissions, while a CBEI should account for all vehicle emissions including out-of-boundary. [Total vehicle emissions for a CBEI could be derived from annual odometer readings by vehicle type - collected during vehicle insurance renewals by ICBC.]	High
Air travel with multiple flights and air travel at airports other than YVR: currently YVR flight data only captures the first leg of flights. [Origin-destination studies at airports could be conducted to determine demand broken down by community (as was done for YVR) and to capture full trip lengths where multiple flights may be taken.]	High

Data Gap or Methodology Enhancement	**Anticipated Significance**
Improved allocation of ferry emissions: currently ferry travel is estimated by pro-rating ferry impacts based on population (see Appendix B for details). [Origin-destination studies for ferry travel would for a more representative allocation of emissions.]	Possibly low for the region and high for specific communities (such as Bowen Island) and would also facilitate better analysis of policy interventions
Cruise ship activities. [This could be filled through adding this travel mode to the TransLink Trip Diary survey or through use of the Lighter Footprint App which is currently under development]	Low
Canadian specific factors for embodied emissions of fuels: currently embodied emissions of fuels are calculated using factors published by the UK government. These are appropriate for international shipping; however, Canadian specific factors should be used for all other fuel consumption. Embodied emissions of Canadian liquid and gaseous fuels are both significantly higher than average.	High
Expanded embodied emissions of materials for transportation: currently only factors for embodied emissions of materials for private and commercial vehicles are included; embodied emissions of materials for rail, ferries, aircraft, off road vehicles and equipment could also be included.	Low

Inventory Frequency

While operating emissions can vary from year to year, some embodied emissions take longer to shift. For example, a car lasts 15 years or more on average, buildings 40 to 75 years on average, and water and sewer pipes last up to 100 years. It also takes time for changes in practises to be reflected in updated Lifecycle Assessment data.

For these reasons we recommend selective updates to a CBEI. Operating emissions, and any embodied emissions that have the potential to change more quickly can be updated annually and embodied emissions that are slower to change could be updated every 5 years.

Urban Metabolism and Ecological Footprint Functionality

The ecoCity Footprint Tool which was used to generate the Metro Vancouver regional CBEI also has capacity to generate an Urban Metabolism (with additional development) and an Ecological Footprint assessment. Metro Vancouver could consider utilizing these metrics in the future to gain a more robust understanding of the ecological demands on nature's services imposed by the region and its residents.

We know that climate change is just one of the planetary boundaries that we are bumping up against. We are hitting resource constraints also. The ecological footprint helps us to estimate and visualize the extent to which we are drawing down the earth's resources in a clear easy to understand way. It calculates how much productive land and sea area an individual population needs to produce all of the materials and energy it consumes, and to handle all of the waste it is generating – this includes carbon emissions and other forms of waste. The ecological footprint and consumption-based emissions are both important metrics for local governments to consider and address.

Utilizing CBEI Results in Policy and Planning

Key priorities for policy intervention can be drawn from the CBEI results, including:

Food represents 19% of the CBEI, with most of the impacts from food being upstream (i.e., from farming); and more than half is associated with animal proteins. These results indicate the need to reduce the upstream GHG impacts of food, through changes in farming practises, reduction in wasted food, shifting to low-emission diets, and improving the efficiency of food production.

Similar to food production, the emission impacts of consumable goods, from a consumption-based perspective, are driven by upstream emissions (comprising 81% of the impacts for this category). This illustrates the importance of decarbonizing supply chains, reducing the overall consumption of 'stuff' and reducing the material and energy intensity of manufacturing.

About two-thirds of the CBEI for buildings and transportation are associated with operating emissions, indicating the continued need for fuel switching, mode shift and efficiency improvements and demand side management policies. As these efforts progress the embodied emission impacts will comprise an increasing percentage of the impact, necessitating consideration of low carbon planning, construction and manufacturing practices as well as continued emphasis on efficient land use that reduces the need to travel. An emphasis on circular economy initiatives that reduce extraction of raw materials and disposal of waste will play an important role in transforming to a low carbon region. Ensuring a thorough understanding of near and long-term GHG emissions impacts of decisions relating to the built environment will be critical to meet current and long-term climate and zero waste / circular economy initiatives, goals and policies. The CBEI and other tools like the Athena Impact Estimator can inform these decisions.

To date there are limited examples of application of CBEI results, but leading local governments have begun early efforts. There are a growing number of BC local governments leading the way, for example:

- City of Vancouver adopted a 'lighter footprint goal' in their Greenest City Action Plan (https://vancouver.ca/green-vancouver/greenest-city-action-plan.aspx)
- City of Vancouver has developed an embodied emissions of materials strategy for buildings, including a goal to reduce embodied emissions by 40% (https://vancouver.ca/files/cov/cov-embodied-carbon-policy-review-report.pdf)
- City of Nelson is undertaking a project to inventory embodied emissions of materials for buildings
- District of Saanich has incorporated CBEI results into their award winning Climate Plan (www.saanich.ca/climateplan)
- District of Saanich is partnering with Bioregional UK and One Earth to engage community stakeholders in focusing their sustainability efforts on priorities identified in the CBEI and ecological footprint results (www.oneplanetsaanich.org)
- Numerous local governments are addressing the resource and climate impacts of food, in particular through addressing food waste (e.g., Metro Vancouver's Love Food Hate Waste campaign)

Appendix A: Comparison of Inventories - CBEI vs Territorial

This appendix summarizes emissions captured in the territorial inventory versus the CBEI.

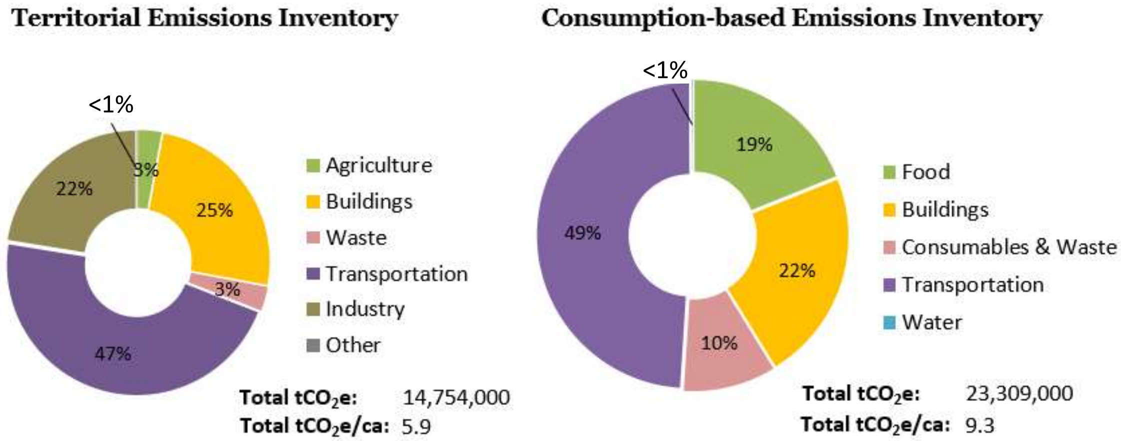

Figure 25: Comparison of Metro Vancouver Region's Territorial GHG Emissions[21] (left) and Consumption-based GHG Emissions (right), 2015

Table 4: Comparison of Metro Vancouver Region's Territorial GHG Emissions[22] and Consumption-based GHG Emissions, 2015

	Territorial GHG Emissions (tCO_2e)	Per Capita Territorial GHG Emissions (tCO_2e/ca)	Consumption-based Emissions (tCO_2e)	Per Capita Consumption-based Emissions (tCO_2e/ca)
Agriculture/ Food	433,996	0.2	4,415,053	1.8
Buildings	3,686,160	1.5	5,194,094	2.1
Waste/ Consumables and Waste	442,117	0.2	2,281,042	0.9
Transportation	6,880,039	2.7	11,399,935	4.5
Water			18,529	<0.1
Industry	3,300,667	1.3		
Other	10,746	<0.1		

[21] Source: updated 2015 Metro Vancouver Emissions Inventory, provided by Metro Vancouver staff
[22] Ibid.

Agriculture / Food

In the territorial inventory, agriculture includes some non-food related emissions from nursery and flower growers that are not captured in the CBEI. The CBEI, however, includes more emission sources from farming such as tilling, which make up a large percentage of emissions. The CBEI includes emissions for all food consumed in the region whereas the territorial inventory includes emissions from production within the region. The operating emissions from transporting imported food are also captured in the CBEI as are the embodied emissions of all fossil fuels used importing food (for example, emissions from extraction and refining fuels).

Buildings

For buildings both the CBEI and territorial inventory capture the operating emissions of buildings within the Metro Vancouver region. The CBEI also captures the embodied emissions associated with the initial construction materials of buildings and the embodied emissions of fossil fuels associated with operating emissions. The territorial inventory captures part of the embodied emissions of fuels as in-boundary fugitive emissions. The territorial inventory includes emissions from burning wood for heating (methane and nitrous oxide only, carbon dioxide is considered biogenic) whereas these emissions are not included in the CBEI.

Waste/ Consumables & Waste

Waste emissions in the territorial inventory include direct emissions from waste at all active and closed landfills within the Metro Vancouver region. The CBEI includes landfill emissions (attributable to the region) from all active landfills that accepted waste from the region in 2015 (Delta and Cache Creek). Both inventories include emissions from waste incineration and wastewater treatment. The CBEI also includes the embodied emissions of both disposed and recycled materials as an estimate of the impact of purchased consumable goods for the inventory year. Direct emissions from composting organics, embodied emissions of waste infrastructure such as the wastewater pipe network, the operating emissions of the waste facilities (which are reported in Metro Vancouver's corporate inventory), and the embodied emissions of all fossil fuels are reported in operating emissions.

Transportation

The CBEI and territorial inventories for transportation both include the same operating emissions from private and commercial vehicles and for non-road (or off-road) equipment/vehicles. For aircraft, rail, and marine vessels the operating emissions differ between the CBEI and territorial inventories. Only in-boundary emissions are captured in the territorial inventory (landing and takeoff for aircraft) whereas the CBEI captures as much of the full trip length as possible. For rail and marine the territorial inventory includes emissions from shipping goods whereas in the CBEI these emissions are reported in food as food-miles and as part of the embodied emissions in consumables. The CBEI also includes the embodied emissions of all fossil fuels reported in operating emissions and the embodied emissions of the materials that make up roads, and private and commercial vehicles.

Water

The CBEI captures the embodied emissions of the fresh water supply system (e.g., dams, roads and pipes), operating emissions from facilities (reported in Metro Vancouver's corporate inventory), and the embodied emissions of all fossil fuels reported in operating emissions.

Industry

The territorial inventory captures in-boundary emissions from industry whereas the CBEI attempts to capture emissions from all goods and services consumed within the Metro Vancouver region. Some of the industrial emissions will be included in both inventories. For example, emissions that occur within the Metro Vancouver region from the production of concrete or refining of fossil fuels, that are also used/consumed within the region, should be captured in both inventories – as direct emissions of industry in the territorial inventory and as embodied emissions of buildings, roads and fuels in the CBEI. Industry emissions in the territorial inventory associated with goods and services that are exported are not included in the CBEI, and industry emissions that are included in the CBEI (as embodied emissions) that occur outside of the Metro Vancouver region are not included in the territorial inventory.

Appendix B: Methodology and Sources

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 reported in operating emissions (for example, from extraction and refining of the fuels) are included. 'Well to Tank' (WTT) emission factors published by the UK government are used for the calculations.

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

Challenges and Opportunities

The UK government publishes these emission factors annually, however, some factors were not available in the 2015 publication (the CBEI year) and therefore the latest release published in 2020 was used.

Operating Energy [Food-Miles] Methodology

To estimate distance travelled for Canadian food, 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-Kilometers

An average food kilometer value 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 distances by destination and origin was taken as the average food-kilometer 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.).

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 average import kilometers (described above) and the total tonnes consumed (described in the Food Production Methodology section).

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.

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

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.

The methodology only considers imported food distances, as a methodology has not been found to include domestic food miles (provincial and inter-provincial), or food miles from farms to processing facilities (which could be domestic or international).

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

As described in the 'Embodied Energy of Fuels [Food Miles] Methodology' section above, 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 published by the UK government are used for the calculations.

Note that fugitive emissions of the natural gas network that are reported in the territorial inventory are assumed to be included within the factors for embodied emissions of fuels used in the CBEI.

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

Challenges and Opportunities

Emission factors published by the UK government are likely appropriate to be used for calculating emissions from international shipping as was done in this inventory for food imports, however, liquid and gaseous fuels used in British Columbia in buildings and transportation are from Canadian sources that have higher than average embodied emissions. Therefore, embodied emissions of fuels for both buildings and transportation will be underestimated in this inventory and research to derive Canadian emission factors would yield more accurate results.

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;[23]
- 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]

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

[23] Note construction and demolition waste is collected in this section but it is to ensure that it is excluded, since C&D waste is already included in LCA factors for buildings

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

Built area for transportation includes road length and paved right-of-way width. 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.

Embodied emissions of vehicle materials are calculated for on-road vehicles (private and commercial) by vehicle type using GHG operating emissions by vehicle type and Life Cycle Assessment factors obtained from literature (Zamel and Li, 2006).

Sources

City of Surrey GIS data available online

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

Zamel and Li. (2006). Life cycle analysis of vehicles Powered by a fuel cell and an internal combustion engine for Canada. Journal of Power Sources, Vol 155, pp.297-310, p. 303

Challenges and Opportunities

Estimates of embodied emissions of materials for BC Ferries, aircraft, off road vehicles and equipment, West Coast Express, Skytrain and other infrastructure are not included in the inventory.

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 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 Metro Vancouver 2015 Territorial GHG Emissions Inventory.

BC Ferries data was limited. Information on passenger origin and destination was not available and subsequently, it is difficult to allocate ferry use to any one region or population especially given the significant tourism use of the BC ferries service. BC

Ferries total projected fuel use was obtained from BC Ferries reports and a portion of the emissions was allocated based on the region's proportion of BC's population. Provincial emission factors were used.

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

Sources

BC Ferries Fuel Strategies Update Report http://www.bcferrycommission.com/wp-content/uploads/2011/04/2014-06-27-FY-14-Fuel-Report.pdf

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

Seabus 2015 fuel use provided by TransLink staff

Challenges and Opportunities

Cruise ship activities could be included with survey data on regional use globally. Embodied emissions for the BC ferries fleet could be included with more research.

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]

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

APPENDIX C: LCA DATA FOR CONSUMABLES AND WASTE

The following presents the life cycle assessment data for the consumables by material type as originally developed for Dr. Moore's PhD research in tCO_2e/tonne of product.

Table 5: Life Cycle Assessment Data for Consumables by Material Type (tCO_2e/tonne of product)

Detail by Consumption	**tCO_2e/product**
Paper	
Printed Paper	0.70
News Print	0.85
Cardboard and Boxboard	0.66
Telephone Directories	0.70
Other	0.70
Plastic	
Film (bags)	3.38
PET	4.93
HDPE	2.92
PVC	1.99
Other	3.38
Organic Waste	
Food waste (not to include in the EF)	
Yard and Garden	
Wood Waste	0.72
Textile	15.00
Rubber	6.37
Other	
Metals	
Ferrous Food/Drink Packaging not Recycled	1.80
Ferrous Other	1.80
Non-Ferrous and Bimetallic	12.82
Glass	
Food/Drink Packaging	0.65
Other	0.65
Household Hygiene	
Diapers	3.20
Sanitary Napkins/Tampons	3.20
Other	3.20
Hazardous material Container	12.82
Electronic waste	3.38
Recycled Materials	
	tCO2e/product
Fibre paper	0.83
Newsprint	
cardboard	
Mixed paper	
Glass	0.65
Metal	1.53
Plastic	1.07