Nanaimo 2021 Consumption-Based Ecological and Carbon Footprint Assessment

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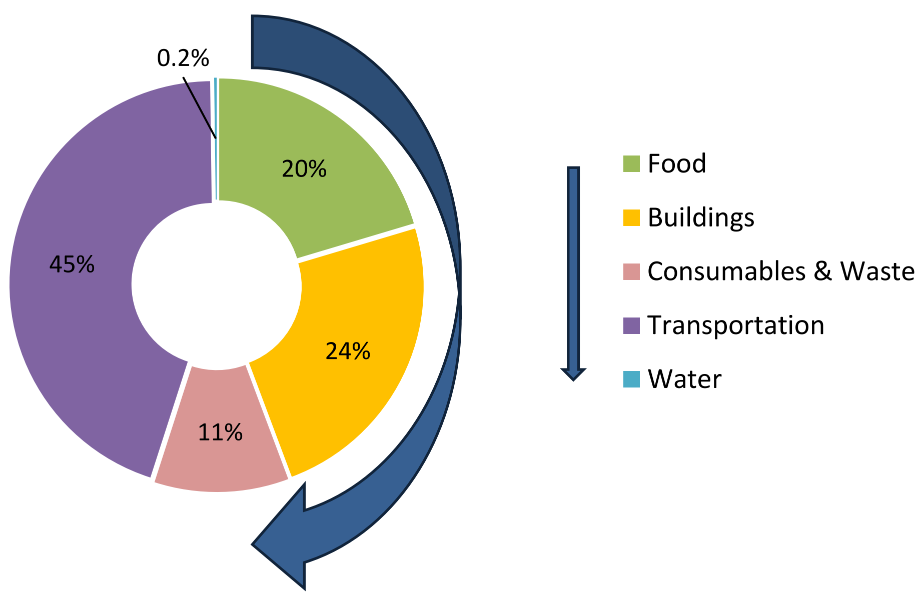
Acknowledgments, Disclaimer and Conditions

This document titled 'Nanaimo 2021 Consumption-Based Ecological and Carbon Footprint Assessment' was prepared by CHRM Consulting for the City of Nanaimo. Authors include Ryan Mackie and Cora Hallsworth. The inventory was created using the ecoCity Footprint Tool, developed by Dr. Jennie Moore.

While the information and data in this report are believed to be accurate, they are provided "as is" without warranty of any kind, whether express or implied.

Guidance for Reading Charts in this Report

Some of the pie charts in this report have extensive detail. For ease of viewing, note that the categories rotate clockwise around the pie chart, matching the order presented in the legend.



Abbreviations

CBEI	Consumption-based emissions inventory
CO_2/CO_2e	Carbon dioxide / Carbon dioxide equivalent
EF	Ecological footprint
gha	Global hectares
gha/ca	Global hectares per capita
GHG	Greenhouse gas
GPC	Global Protocol for Community-Scale Greenhouse Gas Emission Inventories
LCA	Life Cycle Analysis
tCO_2e	Metric tonnes carbon dioxide equivalent
tCO_2e/ca	Metric tonnes carbon dioxide equivalent per capita

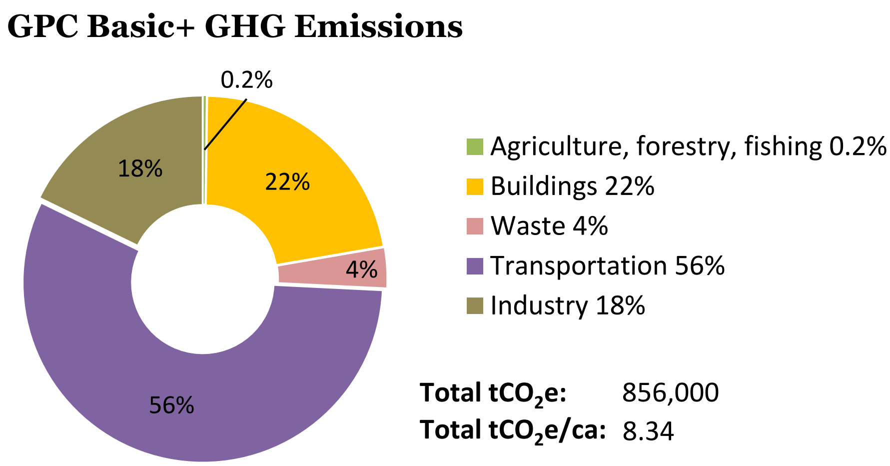
Definition of Terms

Consumption-based emissions inventory (CBEI)	A greenhouse gas emissions inventory that includes emissions released to produce goods and services consumed within a region, regardless of where they were originally produced. That is, it estimates global emissions resulting from local consumption habits.
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 (EF)	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, measured in global hectares (gha).
ecoCity Footprint Tool	A tool developed by Dr. Jennie Moore, with the capacity to create multiple outputs: an urban metabolism, a sectoral 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	The greenhouse gas emissions associated with embodied energy, which include 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.
Global Hectare	A biologically productive hectare with globally averaged productivity.
GPC Basic+	A GHG reporting standard defined in the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories.
Operating Energy	The energy used in the function of a product, building, vehicle, etc.
Operating Emissions	The greenhouse gas emissions associated with operating energy.
Sectoral Inventory	Typically includes GHG emissions from direct sources within a region, grid supplied energy and waste handling.
Urban Metabolism	A study of the flow of energy and materials through the urban system.

Executive Summary

This report presents Nanaimo's 2021 consumption-based emissions inventory (CBEI) and ecological footprint (EF) assessment.

The CBEI and EF complement Nanaimo's GPC Basic+ greenhouse gas (GHG) emissions inventory. These two inventories will help the community understand the impact of local consumption habits on global emissions and land use.



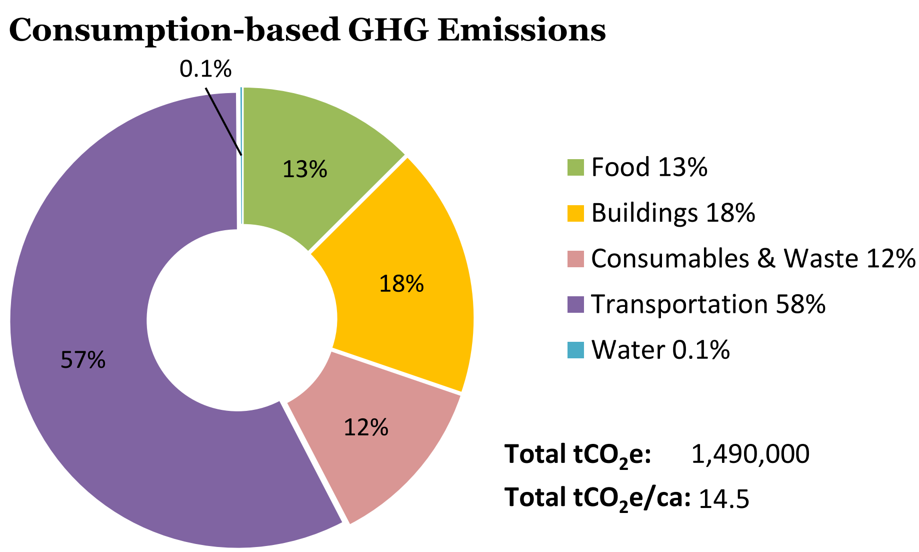


Figure 1: City of Nanaimo GPC Basic+[1] (top) and Consumption-based (bottom) GHG Emissions, 2021

[1] GPC Basic+ reporting categories have been shifted to align with the CBEI categories to allow for direct comparison.

Nanaimo's 2021 CBEI is estimated at ***1,490 ktCO2e***, which is more than 1.7 times greater than the GPC Basic+ GHG emissions inventory of 856 ktCO2e (Figure 1). Nanaimo's EF for 2021 is estimated at ***5.0 Earths*** (Figure 2) including senior government[2] impacts.

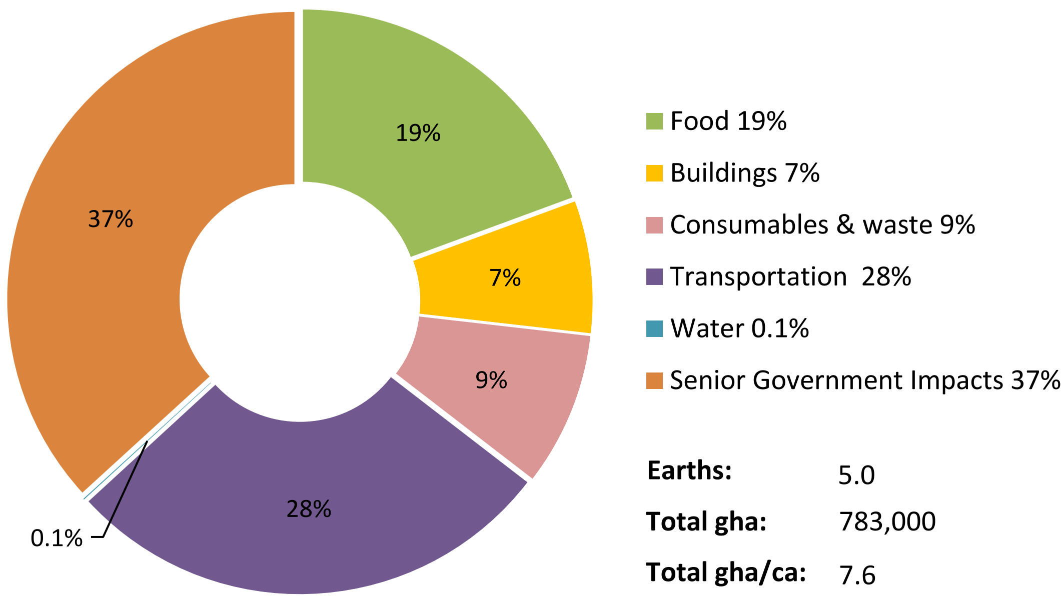


Figure 2: Ecological Footprint for the City of Nanaimo including National and Provincial Impacts, 2021

Transportation emissions are by far the largest contributor to the 2021 CBEI. For the EF, after senior government impacts, the largest impact categories are transportation, followed by food. Transportation has a lower impact on the EF than the CBEI, whereas food has a higher impact on the EF than the CBEI. This is due to the high greenhouse gas (GHG) intensity of the transportation sector and high land intensity of the agricultural sector.

The CBEI and EF identify priorities for action, for example:

- Complete compact communities
- Infrastructure for comprehensive active transportation network, electrified transit, and zero emission vehicles

[2] National and provincial government impacts are from infrastructure and services provided to citizens that are not captured at the local level such as highways, military, health care, coast guard, administrative, etc. They were estimated by extracting data from national inventories (excluding local impacts).

- Efficient, high density low carbon buildings utilizing 100% renewable energy and minimized embodied carbon
- Food waste reduction, low carbon diets, and facilitate low carbon, local (including urban) agriculture and gardening
- Circular economy (e.g., share/reuse/repair) opportunities

Given that we are already at risk of exceeding climate tipping points, aggressive GHG reduction targets are recommended: aimed at becoming net zero as soon as possible and followed by net negative (carbon dioxide removal). A consumption-based approach suggests that 'consumer societies' should be held accountable for a greater proportion of global emissions. Consumption-based emission targets would more closely reflect a fair-share approach to GHG emissions reductions and carbon dioxide removal.

About this Report

This report presents detailed 2021 consumption-based emissions inventory (CBEI) and ecological footprint (EF) results for the City of Nanaimo. It also includes a high-level comparison to the City's 2021 GPC[3]. It contains:

- Background on ecological footprinting and consumption-based emissions inventories
- Inventory scope and methodology
- City of Nanaimo 2021 consumption-based inventory results and comparisons
- Priority actions and factors for selecting consumption-based targets
- Detailed inventory methodology

Background

Understanding the Ecological Footprint and the Consumption-based Emissions Inventory

Globally, we are exceeding our planet's ecological and climate thresholds, meaning that we are emitting more emissions than can be reabsorbed and using more resources than our planet can sustainably regenerate. In Canada, as with other affluent countries, we are taking far more than our fair share. There is also disparity within our communities, with the affluent contributing disproportionately to a community's footprint. Our goal must be to achieve 'One Planet Living', where we are living within the limits of our planet, in a fair and equitable way.

Sectoral and Consumption-Based Emissions Inventories

Since the late 1990s, governments have typically created greenhouse gas (GHG) emissions inventories using an in-boundary or *sectoral* approach. These inventories evaluate emissions from sources within a particular region, and where relevant include emissions from out-of-region grid electricity and waste management.

[3] The Global Protocol for Community-Scale Greenhouse Gas Emission Inventories.

This sectoral approach does not provide a complete picture of a community's impact on global climate change. It misses the climate impacts associated with the many goods a community consumes, because many of them 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. In contrast, the *CBEI* quantifies all consumption-related GHG emissions attributable to a population.

It remains important to track local emissions through the sectoral inventory, for example, to monitor the emission intensity of local industrial and commercial activity. However, consideration of consumption-based emissions facilitates an understanding of global emissions resulting from local consumption habits. The CBEI will 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. The distinction between the sector-based inventory and the CBEI is visualized in Figure 3.

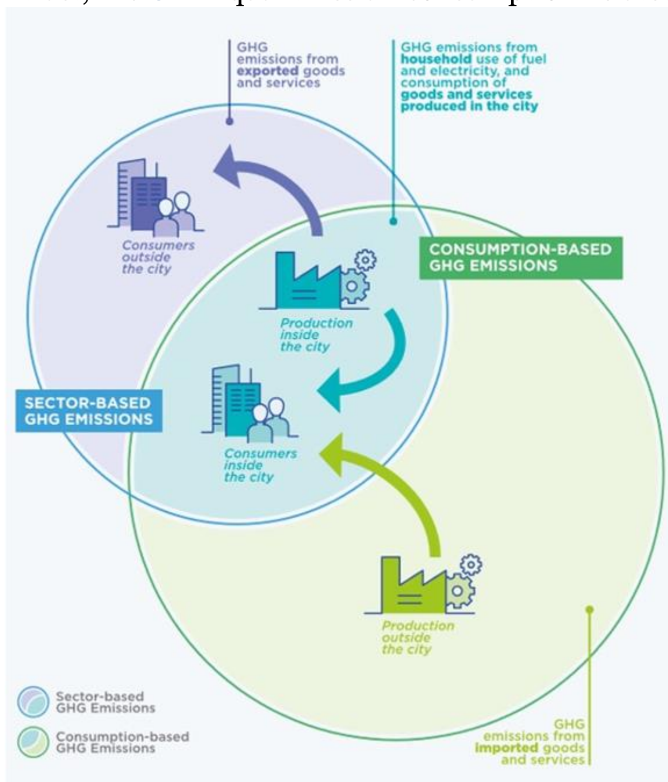


Figure 3: Comparison of Sector-based Emissions with Consumption-Based Emissions

The Ecological Footprint

In contrast to the GHG emissions inventories discussed above, the ecological footprint is a land-based metric measured in terms of global hectares (gha). It is an estimate of how much biologically productive land and water area an individual or population is depending upon to produce all the resources it consumes and to absorb the CO_2 emissions it generates. It helps us to estimate and visualize these impacts in a clear, easy to understand way. Typically, we find that Canadian communities are depending on areas many times larger than the physical space they occupy to produce all the energy, goods, and other materials we use, and to handle all of the waste we are generating.

Based on the current global population and biological productivity levels, *an average of 1.52 gha is available for each person on the planet*.[4] But, globally we are in overshoot, using an average of

[4] We also need to set aside land for nature, thus a target of 1.52 gha/person should be considered a minimum threshold.

2.6 gha per person. This means we are depending on the equivalent of 1.7 planets worth of resources every year. In other words, we are drawing down the resources of the planet faster than they can be regenerated.

The ecological footprint and consumption-based inventory results shed light on the impacts of outsourcing the production of goods that we consume to other regions: it evaluates the full lifecycle impacts that result from consumption within a region. Explore how these types of inventories compare in the schematic in Figure 4.

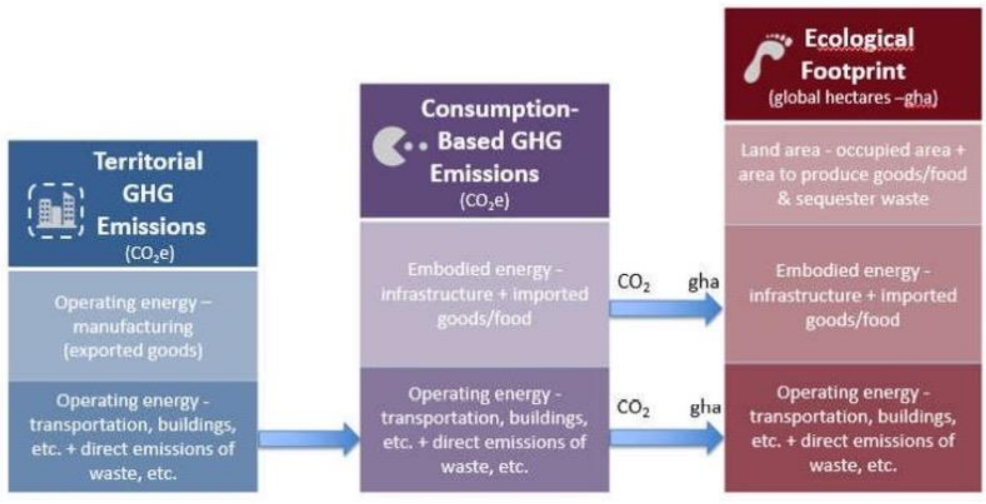


Figure 4: Comparison of the GHG Emission Inventories and Ecological Footprint Approaches

Inventory Scope and Methodology

The footprint assessment for the City of Nanaimo was developed using the ecoCity Footprint Tool (the Tool, see: www.ecocityfootprint.org). The Tool, developed by Dr. Jennie Moore, has the capacity to create multiple outputs: a sectoral greenhouse gas emissions inventory, a CBEI,[5] an EF[6] and with additional development, an urban metabolism.

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 dozens of communities.

[5] A consumption-based emissions inventory includes emissions released to produce goods and services consumed within a region, regardless of where they were originally produced. That is, it estimates global emissions resulting from local consumption habits.
[6] 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.

Global Footprint Network, C40 Cities, and other organizations conducting EFs and 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 (Figure 5).

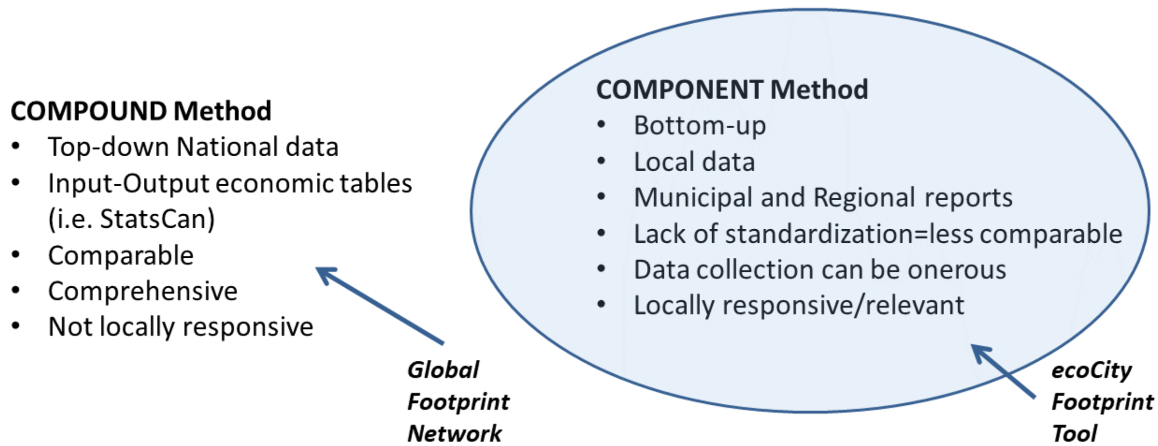


Figure 5: Two methods for calculating the Ecological Footprint

The Tool facilitates the use of community and regional-scale data sources, and in cases where local data is not available, assumptions or proxies are utilized. The key drawback to the component approach used by the Tool is that there can be data gaps and thus under-estimates of EF and GHG emissions compared to the inventories generated with a compound (top-down) methodology. However, use of consumption (activity) data[7], collected through an urban metabolism study,[8] provides advantages for local government planning as it can directly link policy intervention to emissions at the local government scale.

With its focus on local data, the Tool is aligned with the typical spheres, or categories, of municipal planning – buildings, transportation, waste and water; a fifth category – food – is also included, which is of growing interest to municipalities.

Data is collected on materials, embodied energy, operating energy, and built area for each of these categories (Figure 6). They are each evaluated by sector – residential, institutional, commercial, and light industrial ((I)CI).

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

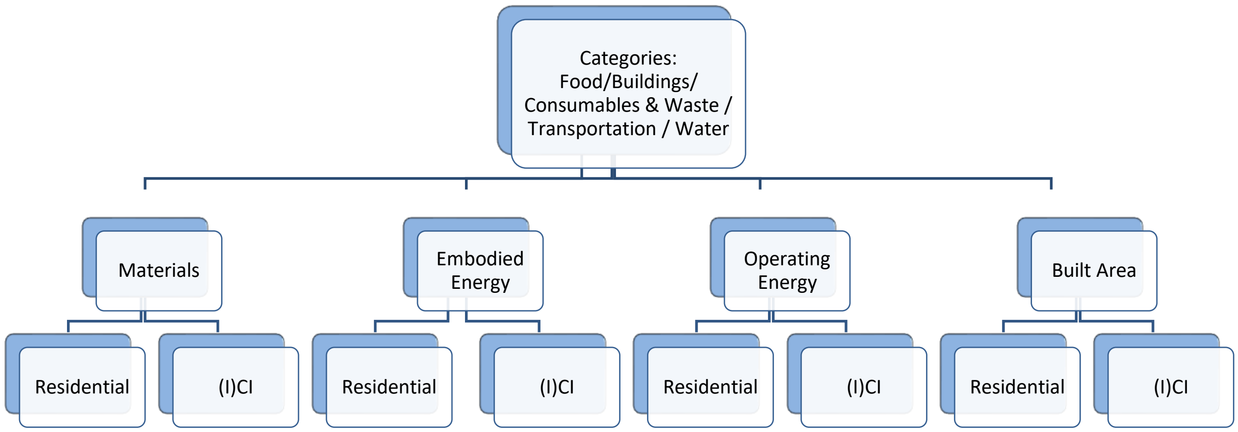


Figure 6: Data Inputs

Data Sources

Most of the data used to create the inventory was derived from local sources with national data used where local data was unavailable as summarized in Table 1 below. Operating and direct emissions are included from the *City of Nanaimo 2021 GPC BASIC+ Community Greenhouse Gas (GHG) Emissions Inventory Report*, where available (for details see Appendix A: Methodology and Sources).

Table 1: Local vs National/Provincial Data Sources

Inventory Data Source	
National/Provincial	**City Data/Local Reports**
• Food consumption • Food transport • Air Travel • Refrigerants (etc.) • Off-road fuel	• Built Areas • Building stock • Infrastructure (pipes, roads, etc.) • Waste tonnage and composition • Operating emissions (buildings and transportation)

Key Assumptions and Limitations

An overview of the data inputs required to generate the ecological footprint and CBEI, and key assumptions and limitations are presented in Table 2 below. A detailed overview of the methodology, data sources, and challenges and opportunities are presented in Appendix A: Methodology and Sources.

Table 2: Key Assumptions and Limitations

Category	Details	Key Assumptions and Limitations
Food	Embodied energy associated with food production (energy used for farming) and operating energy to transport imported food.	Food consumption 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), a regional food survey, or working directly with food wholesalers and distributors. Food transport distances are estimated for food imported to Canada and domestic transport based on national/ provincial statistics and a Metro Vancouver case study as a proxy.
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 archetypes using the Athena Impact Estimator. Embodied emission factors associated with maintenance, renovations and furniture over the lifespan of buildings are not included. Data, although limited, suggests this could more than double the impact of materials for commercial buildings.[9] Embodied emissions impacts are amortized over the lifespan of the building. Estimates for building lifespan are based on national statistics. Emissions from refrigerants, foams and aerosol cans are derived from estimates from the Province of BC, however these estimates are aggregated including industrial use which should not be included in a consumption-based inventory.
Consumables and Waste	Direct emissions from waste facilities (i.e., landfilled, incinerated, composted, and wastewater). Embodied energy of disposed and recycled materials (i.e., consumable goods). Embodied energy of wastewater treatment system.	The total quantity of goods consumed in a given year is derived from waste and recycling numbers, assuming that the majority of materials consumed are disposed within the year, and/or that there is a steady flow of durable goods disposed every year equivalent to the new durable goods supply entering the region. Solid waste data is based on a 2022 waste composition audit and 2022/2023 tonnages for the regional district. The Tool does not include life cycle analysis (LCA) values for all recycled material types (only recycled paper, plastic, glass, and metal are included).

[9] Research on impacts of mechanical, electrical, plumbing and tenant improvements over a commercial building's lifespan are published by Carbon Leadership Forum (https://carbonleadershipforum.org/office-buildings-lca/).

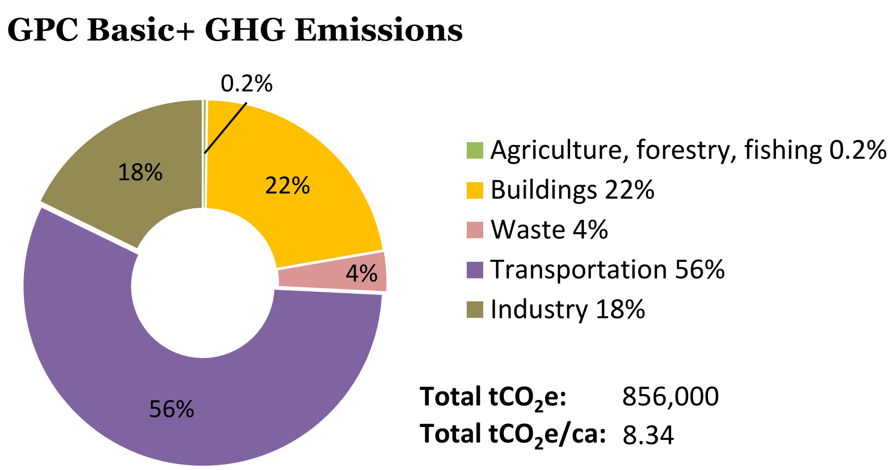
Category	Details	Key Assumptions and Limitations
Transportation	Embodied energy associated with vehicles, fuels, and roads. Operating energy associated with transportation (fuel use for on-road vehicles, marine, aviation, and off-road vehicles/equipment).	Paved areas such as parking lots were not captured. Air travel operating emissions are based on the National Energy Use Database (NEUD) for the Canadian aviation sector. Comparison of the NEUD data to air travel studies suggests that it provides a reasonable approximation of a community's total air travel impact (including out-of-boundary travel). Due to lack of data, embodied energy of materials for off road vehicles and equipment were not included in this inventory.
Water	Embodied energy of materials associated with water infrastructure.	Embodied energy of the water pipe network was included. The long lifespan of this infrastructure results in a small annual impact 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

City of Nanaimo Inventory Results

This section details the City of Nanaimo's CBEI and ecological footprint results, summarizing total impacts, and impacts by category. It also compares results with Nanaimo's GPC Basic+ emissions inventory.

Comparison of 2021 Inventories - CBEI vs GPC Basic+

The 2021 CBEI for Nanaimo is estimated at *1,490 ktCO2e*, and GPC Basic+[10] GHG emissions are estimated at 856 ktCO_2e (Figure 7 and Table 3).



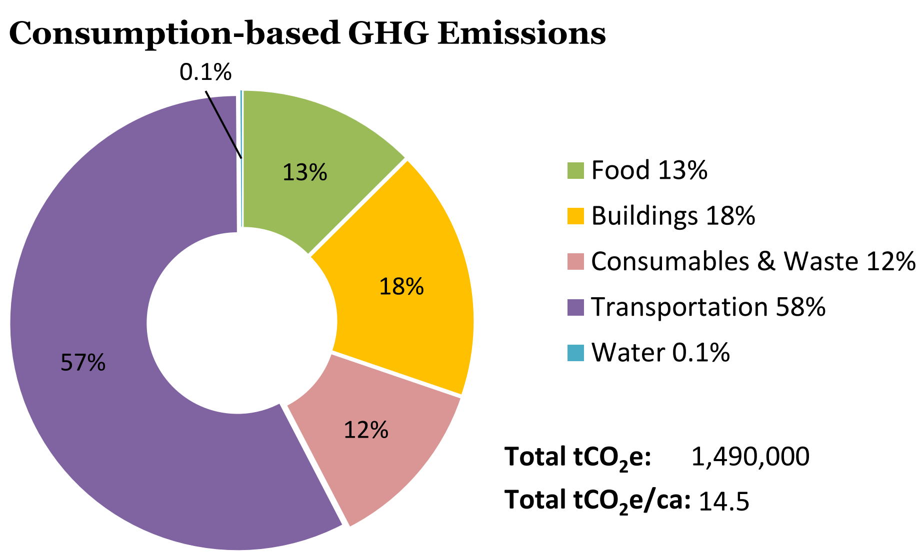


Figure 7: City of Nanaimo GPC Basic+[10] (top) and Consumption-based (bottom) GHG Emissions, 2021

[10] GPC Basic+ reporting categories have been shifted to align with the CBEI categories to allow for direct comparison - 'Buildings' also includes IPPU emissions (sources are primarily commercial refrigeration and HVAC); 'Waste' also includes Energy Industry emissions which is from utilized landfill and wastewater gas; 'Industry' is Manufacturing Industries and Construction which is emissions from natural gas processing.

The overall contribution of transportation to the CBEI and GPC emissions dominates in terms of percentage (56% of GPC emissions and 57% of the CBEI). Also, food, and consumables and waste, make up a much larger percentage in the CBEI compared to agriculture and waste in the GPC inventory.

The difference between the two inventories 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 (from natural gas processing) included in the territorial inventory that are excluded from the CBEI, because they are associated with exported goods.

The CBEI is more than 1.7 times larger than the GPC Basic+ inventory (2.1 times larger, excluding industrial emissions) – as is typical of a 'consumer' community that has significant out of boundary impacts (e.g., imports and travel).

Table 3: Comparison of City of Nanaimo GPC Basic+[10] and Consumption-based GHG Emissions, 2021

	GPC Basic+ (tCO_2e)	*CBEI (tCO_2e)*	*Difference*
Agriculture, forestry, food	1,635	187,594	185,959
Buildings	189,030	263,512	74,482
Waste / Consumables	29,885	180,780	150,895
Transportation	482,924	856,605	373,681
Industry	152,259	NA	-152,259
Water	NA	1,613	1,613
Total	**856,000**	**1,490,000**	**634,000**

Detailed 2021 CBEI Results

The overall 2021 CBEI is discussed above in comparison with the GPC Basic+ inventory – see Figure 7 and Table 3.

CBEI of Food

As Figure 8 below shows, the majority of emissions associated with food are due to production activities[11] (91%), with only 9% due to the transport of food (i.e., food miles). Transport of food emissions include 6% from operating energy (i.e. 'tailpipe' emissions from transport) and 3% from embodied energy of fuels (i.e. upstream emissions from the extraction, processing and transport of the fuel used). This highlights the need to focus on the energy and emissions intensity of food production.

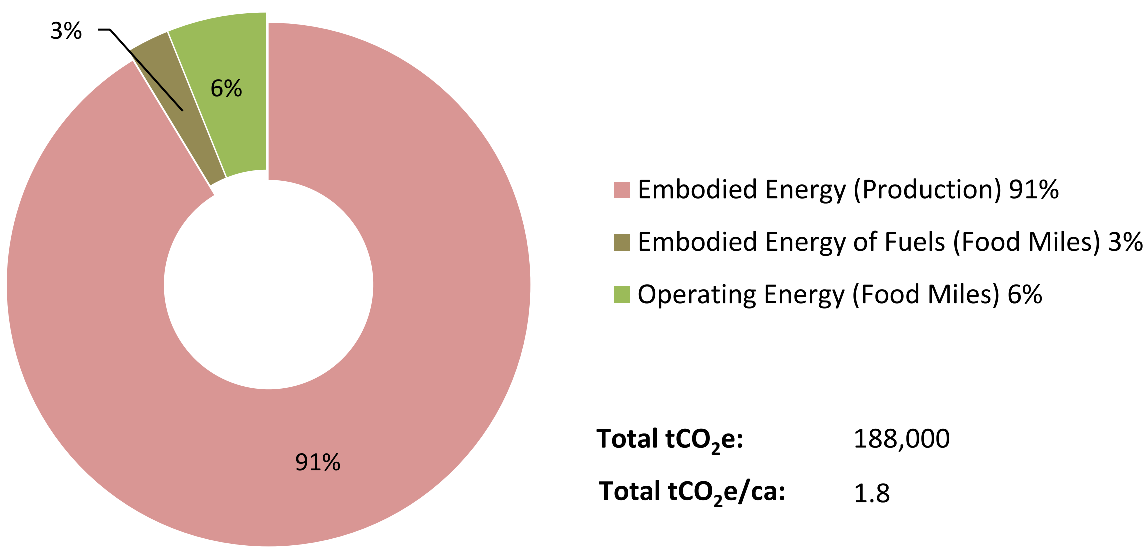


Figure 8: CBEI of Food for the City of Nanaimo, 2021

The relative impact of food miles varies significantly by food type and 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). This suggests that with a

[11] Food production activities include farming (soil management, manure, fertilizer, equipment, etc.) and primary processing of foods such as separating grain.

shift to lower impact diets (e.g., vegetarian and vegan), food miles would become a more significant contribution to the footprint for food[12].

Analyzing the energy and emissions intensity of food production also highlights the impact of food waste. In Canada, about half the food we produce is wasted, representing a large potential to lower impacts from food. Shorter supply chains and local food production may be part of the solution to tackling food waste since a significant portion of food waste occurs in the supply chain.

Experimental farms are developing practices to reduce emissions 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. Research on dietary supplements for livestock is also showing enteric fermentation can be drastically reduced. These advances in lower impact farming are expected to reduce emissions from production, which could also result in a shift in the relative impact of food miles (food miles would make up a greater proportion of the impact).

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 9 shows that, about 60% of the CBEI for food are attributed to animal proteins – particularly meat, and dairy. Within the dairy category, the predominant driver is cheese due to the intensity of cheese production.

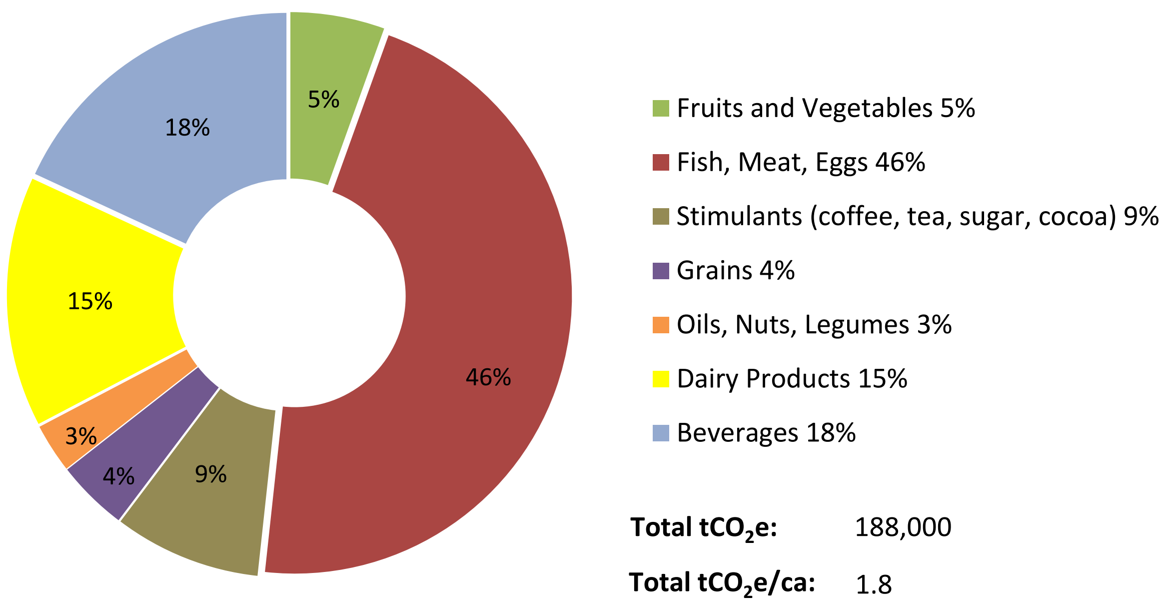


Figure 9: CBEI of Food by Type for the City of Nanaimo, 2021

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

The impacts of food can also be considered in terms of GHG emissions intensity per amount of protein provided, as shown in Figure 10, showing that beef, lamb and goat have the greatest impact per gram of protein.

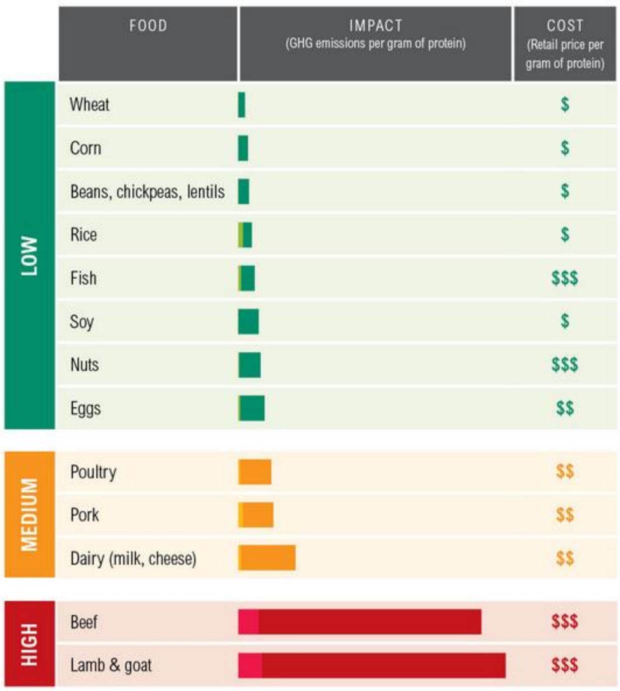


Figure 10: World Resources Institute Protein Scorecard

CBEI of Buildings

The impacts of buildings are currently dominated by operating energy, as shown in Figure 11. As energy efficiency improves and fuel switching continues, operating and embodied emissions of fuels will go down, while the significance of embodied emissions of materials[13] will increase.

The small contribution of commercial buildings to embodied emissions of materials 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 residential apartments) and 65 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 reducing the material intensity of buildings by adopting circular building practices to minimize raw resource extraction and waste disposal, 'right-sizing' buildings for their intended use, and extending lifespans by constructing adaptable buildings. The ecoCity Footprint Tool uses the Athena Impact Estimator to generate embodied emissions estimates. Tools like the Impact Estimator can also be used by local governments to evaluate embodied emissions impacts of projects on a building-by-building basis.

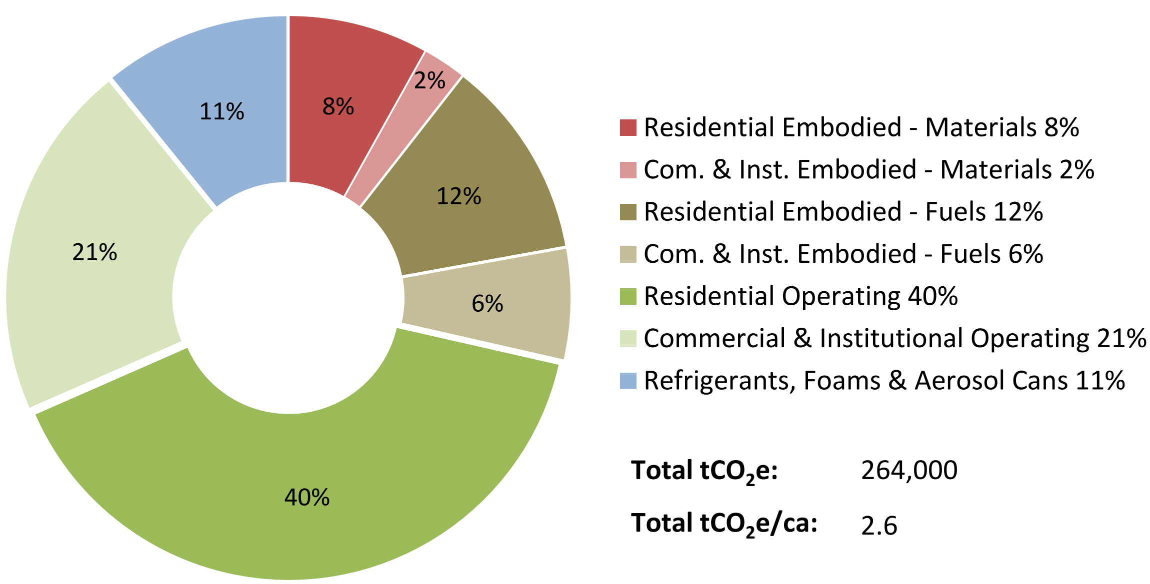


Figure 11: CBEI of Buildings for the City of Nanaimo, 2021

[13] Embodied emissions of materials are emissions associated with the production and transport of building materials.

As shown in Figure 12 below, the majority of impact from buildings are attributable to the residential sector, with light industrial, commercial and institutional sector contributing about one-third. Emissions from production and consumption of halocarbons, SF6 and NF3 (e.g. refrigerants, foams, aerosol cans, etc.) are not disaggregated by sector[14], however it is anticipated that the contribution from the residential sector is relatively low.

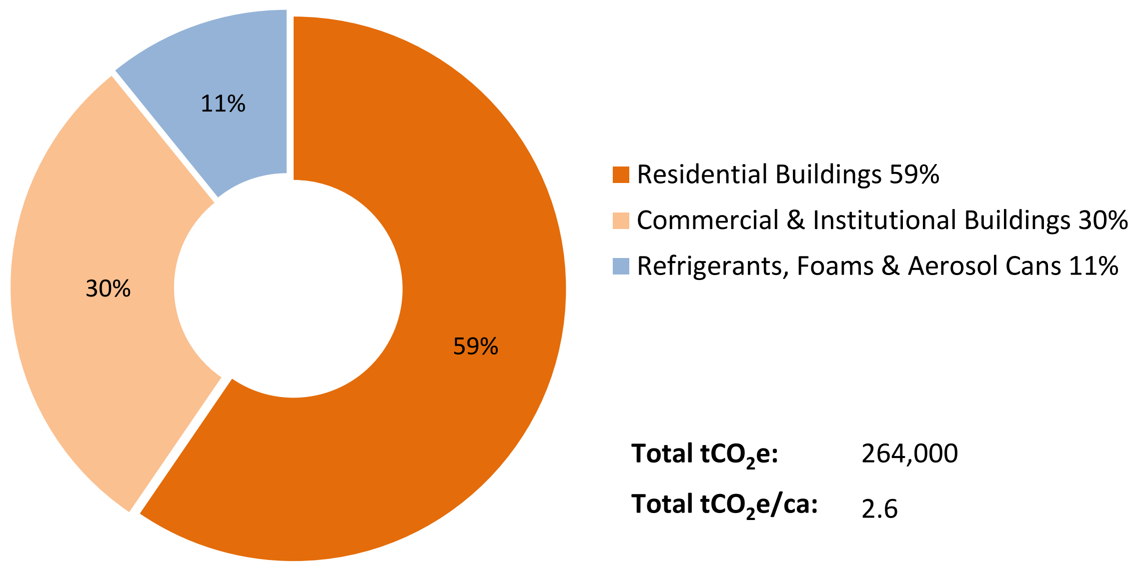


Figure 12: CBEI of Buildings by Type for the City of Nanaimo, 2021

[14] Includes industrial emissions (industrial emissions associated with exported goods should not be included in a consumption-based inventory).

CBEI of Consumables and Waste

Embodied impacts are the dominant driver of consumables and waste emissions at 83%; this includes 77% from embodied energy of materials disposed (i.e. emissions associated with producing the materials that are disposed of in landfill), and 6% from embodied energy of materials recycled (i.e. emissions associated with producing the materials that are recycled). Only 17% of the impact in this category is due to impacts directly resulting from disposal of materials - see materials disposed (direct emissions from landfill) and liquid waste (direct emissions from liquid waste) in Figure 13.

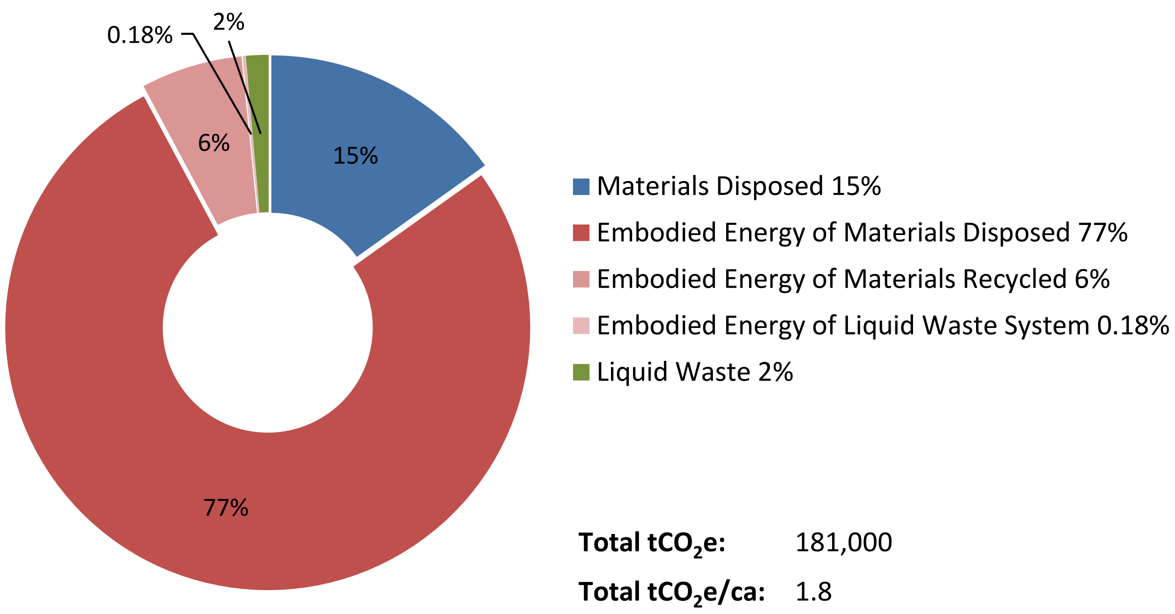


Figure 13: CBEI of Consumables & Waste for the City of Nanaimo, 2021

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 impacts analyses suggest the best tactic to yield dramatic emissions 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.

Figure 14 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 non-compostable organics[15] (46%), followed by plastics (17%). Textiles make up approximately 90% of the impact of the non-compostable organics category.

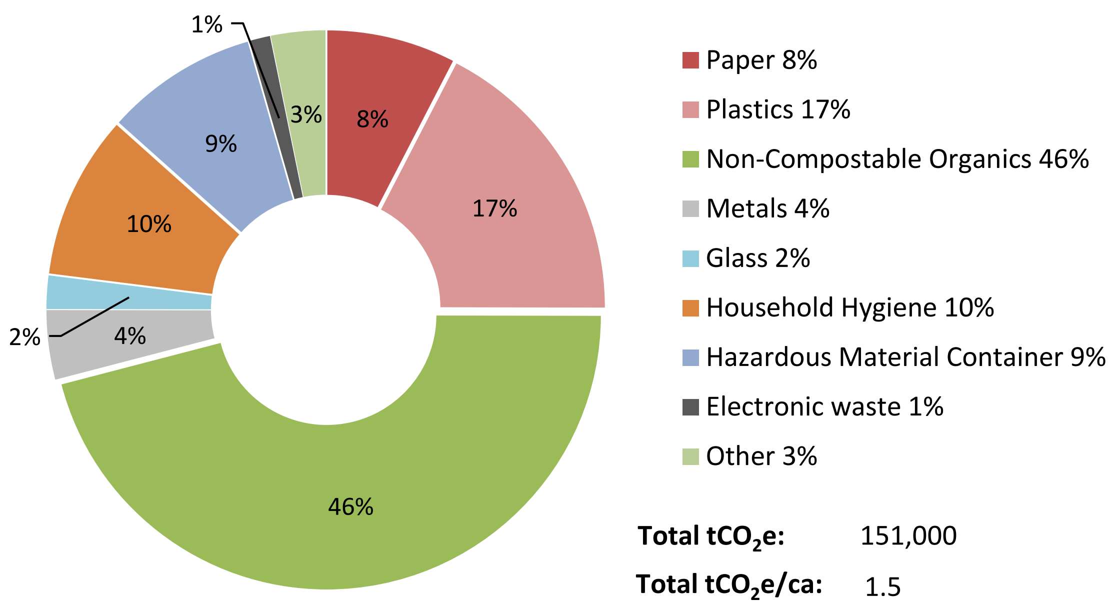


Figure 14: CBEI of Consumables & Waste by Material Type for the City of Nanaimo, 2021

[15] Non-compostable organics includes natural fiber textiles, rubber, and non-demolition wood waste.

CBEI of Transportation

Operating emissions are the largest contributor to the transportation CBEI, representing 64% of the total (Figure 15). If the embodied emissions of fossil fuels (emissions from extraction, processing and transport) are included, the impacts of fuels account for 94% of this category. However, as the transportation fleet continues to electrify, the embodied emissions of materials will become increasingly significant.

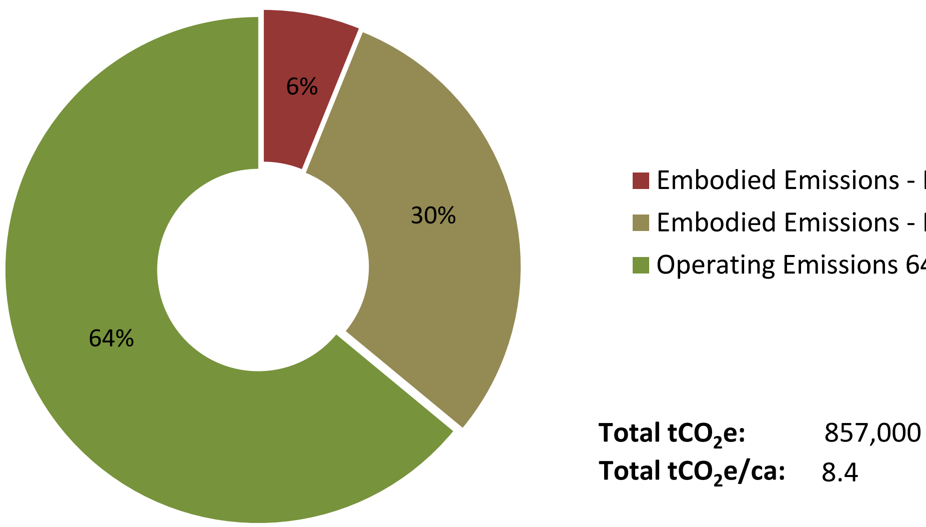


Figure 15: CBEI of Transportation for the City of Nanaimo, 2021

Figure 16 shows the impacts of embodied emissions of materials and fuels from Figure 15 in greater detail. Light duty vehicles make up the majority of the embodied impact at 63% of the total. The quantity of materials in off road equipment and vehicles as well as the impact of materials of some watercraft could not be estimated within the scope of this study (data was not available).

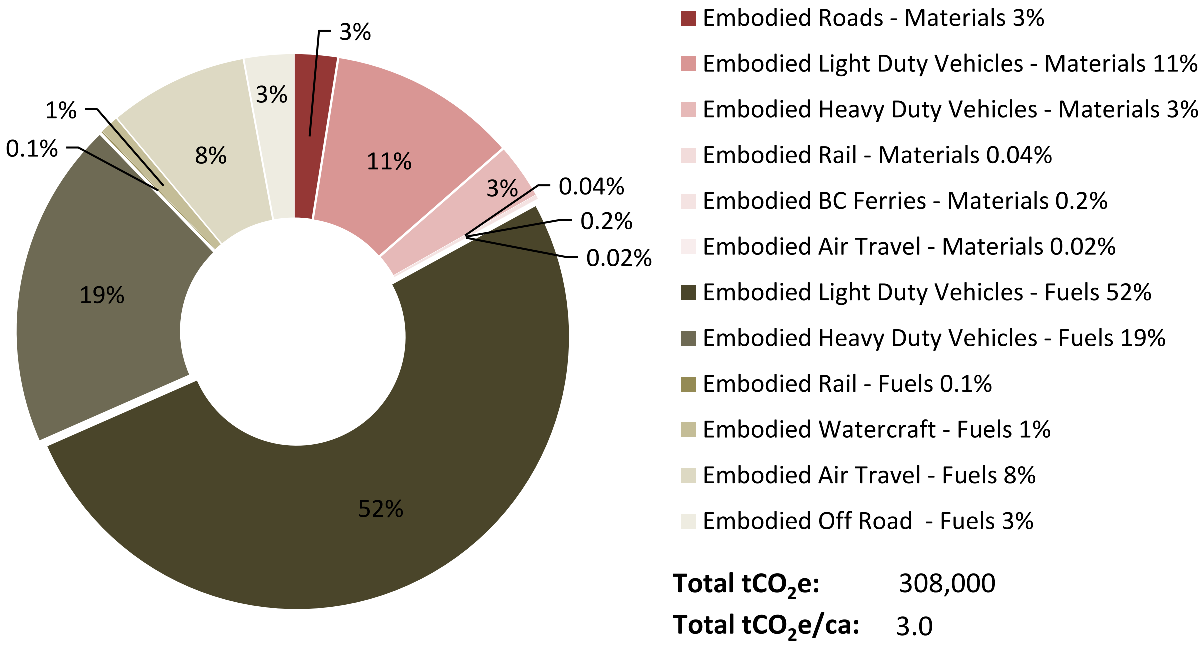


Figure 16: CBEI of Transportation (Embodied Emissions) for the City of Nanaimo, 2021

Combining the embodied and operating emissions of light duty vehicles, the total impact of light duty vehicles is 59% of the CBEI for transportation (Figure 17). The next most significant categories within the CBEI for transportation are the impacts associated with heavy duty vehicles (24%), and air travel (11%).

The relatively low impact of roads is in part due to the long lifespan of road materials and that these impacts are amortized over their lifespan. One shortcoming of this amortized approach to calculating emissions is that it obscures the opportunity costs of building with conventional concrete and asphalt compared to lower carbon options. With current practices, road materials will yield significant near-term emissions associated with production and construction. Given the current climate emergency it is important to balance immediate and long-term emissions impacts of construction choices.

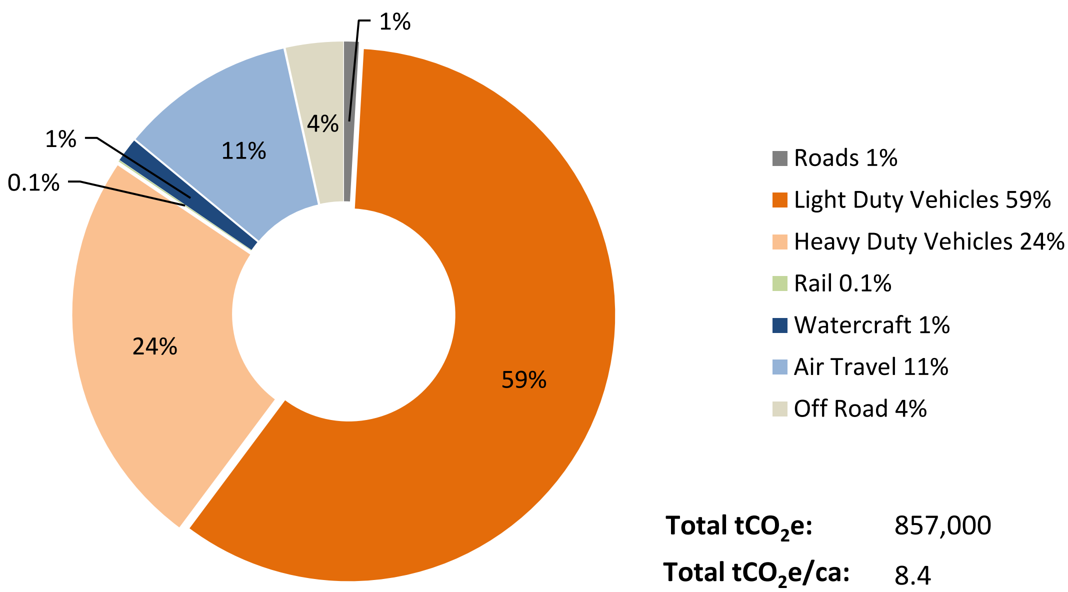


Figure 17: CBEI of Transportation by Type for the City of Nanaimo, 2021

CBEI of Water

The impacts of the fresh water supply pipes and dams resulted in an additional 1,600 tCO_2e in the CBEI, which is negligible overall. This is in part due to the amortization of water supply infrastructure over its long lifespan.

Detailed 2021 Ecological Footprint Results

The ecological footprint (EF) identifies the resource intensity of the community in terms of land and sea area that are required to supply the resources and assimilate the CO_2 emissions from the community.

Nanaimo's ecological footprint is 7.6 gha/ca, including senior government impacts[16] (Figure 18). This means that residents are consuming 5.0 times more of the Earth's resources than what was available in 2021 (1.52 gha/ca) if those resources were to be shared equitably across the world. Put another way, this means that approximately *5.0 Earths* would be required to support the global population if everyone had lifestyles comparable to a City of Nanaimo resident. The ecological footprint would need to be reduced by about 80% to be within the limits of the planet.

By including an estimate for senior government impacts the EF results can be compared directly with 'top down' EFs such as those compiled by the Ecological Footprint Initiative at a national level. For 2021 the Ecological Footprint Initiative calculates Canada's EF at 4.9 Earths, meaning the City of Nanaimo EF is inline with the national average.

At a total of 7,810 km^2, the ecological footprint, including senior government services, is more than 86 times larger than the City of Nanaimo boundary and 142 times larger than the built area.

For the EF, after senior government impacts, the largest impact categories are transportation, followed by food (for the CBEI the highest impacts are due to transportation, followed by buildings– see Figure 7). Food impacts are the category in which results vary most significantly compared to the CBEI. Food is a much higher portion of the EF, compared to the CBEI, largely because of the land intensity of food production, which drives up the ecological footprint.

[16] National and provincial government impacts are from infrastructure and services provided to citizens that are not captured at the local level such as highways, military, health care, coast guard, administrative, etc. They were estimated by extracting data from national inventories (excluding local impacts).

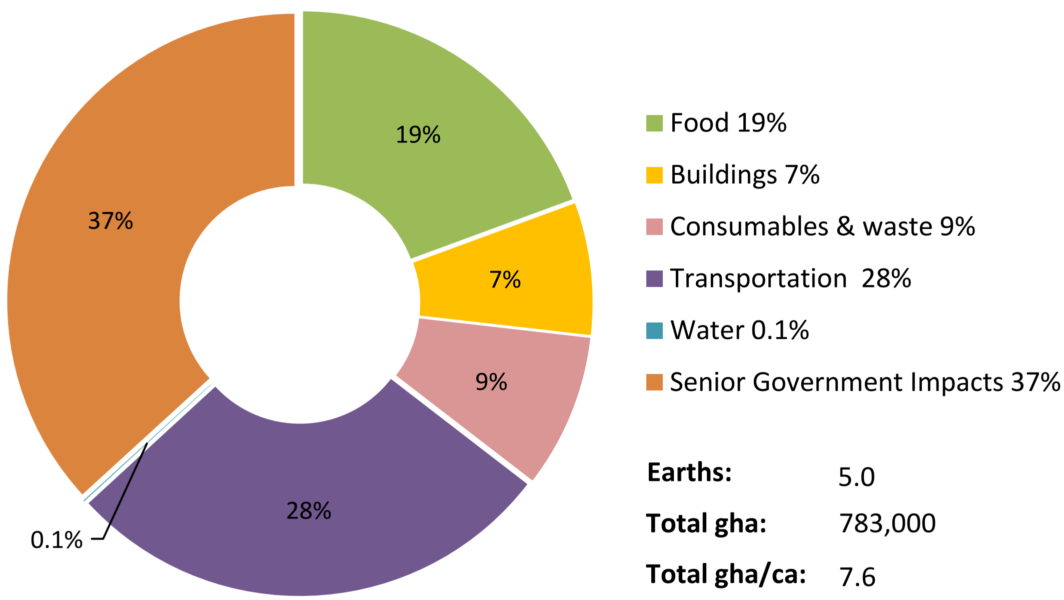


Figure 18: Ecological Footprint for the City of Nanaimo including National and Provincial Impacts, 2021

Table 4: Ecological Footprint for the City of Nanaimo, 2021

	2021 EF (Earths)
Food	0.98
Buildings	0.37
Consumables & Waste	0.43
Transportation	1.39
Water	0.003
Senior Government	1.85
Total	**5.02**

The following sections focus on the unique conclusions drawn from the EF results and on differences between the EF and the CBEI. Conclusions that apply to both the CBEI and EF may not be repeated below, and readers should refer to the relevant sections of the CBEI results for more information.

Ecological Footprint of Food

As Figure 19 below shows, the majority of impacts associated with food are due to production activities[17] (97%), with only 3% due to the transport of food. Transport of food impacts include 2% from operating energy (i.e. 'tailpipe' impacts from transport) and 1% from embodied energy of fuels (i.e. upstream impacts from the extraction, processing and transport of the fuel used). The impact of production is higher in the EF than the CBEI (Figure 8) due to the land intensity of farming which is captured in the EF.

It is also significant that solely with the impacts of food, Nanaimo's EF is already at the capacity of the planet.

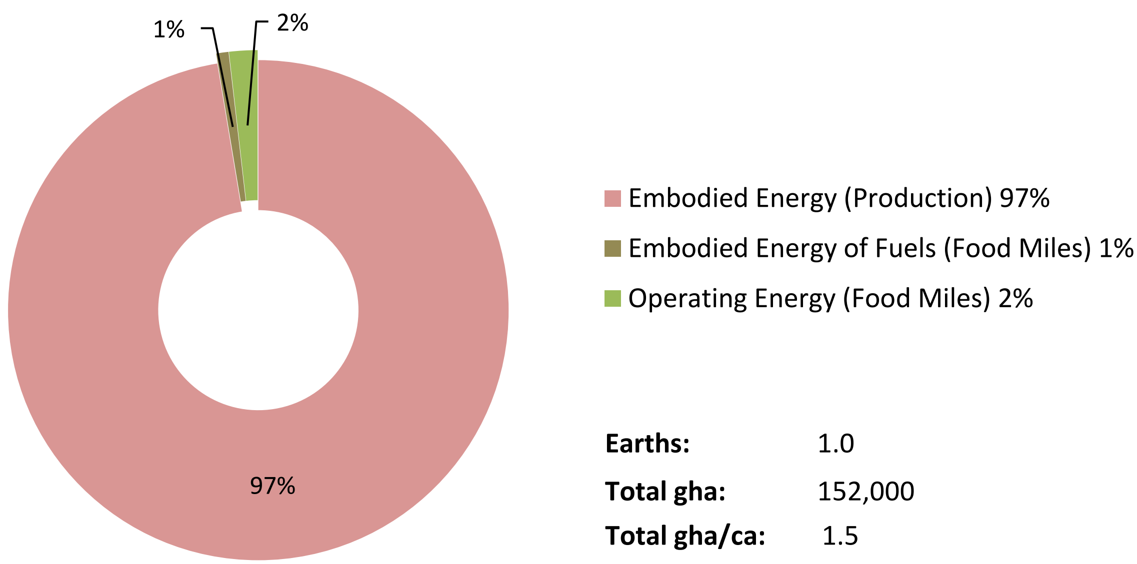


Figure 19: Ecological Footprint of Food for the City of Nanaimo, 2021

[17] Food production activities include farming (soil management, manure, fertilizer, equipment, etc.) and primary processing of foods such as separating grain.

Figure 20 shows that the majority of the EF for food is attributed to animal proteins – particularly meat, and dairy, as is the case with the CBEI (Figure 9).

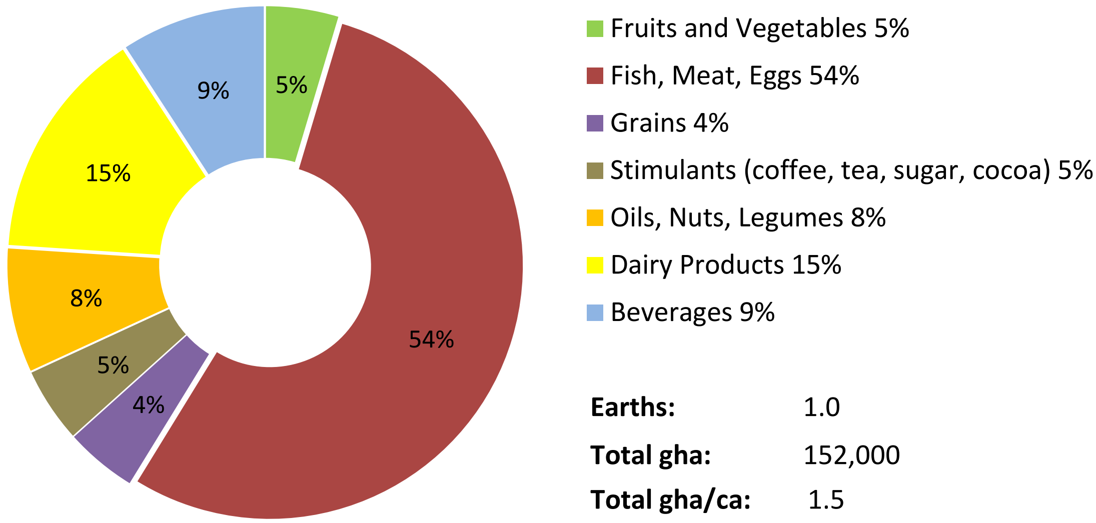


Figure 20: Ecological Footprint of Food by Type for the City of Nanaimo, 2021

Ecological Footprint of Buildings

The impacts of buildings are dominated by operating energy, shown in Figure 21, as is the case for the CBEI (Figure 11). The EF also includes the impacts of built area (which the CBEI does not) - that is the physical area that is occupied by buildings, landscaping, etc. The EF does not include the impacts from refrigerants, foams and aerosol cans (which the CBEI does include) since typical EF methodologies only include carbon dioxide (CO_2) emissions.

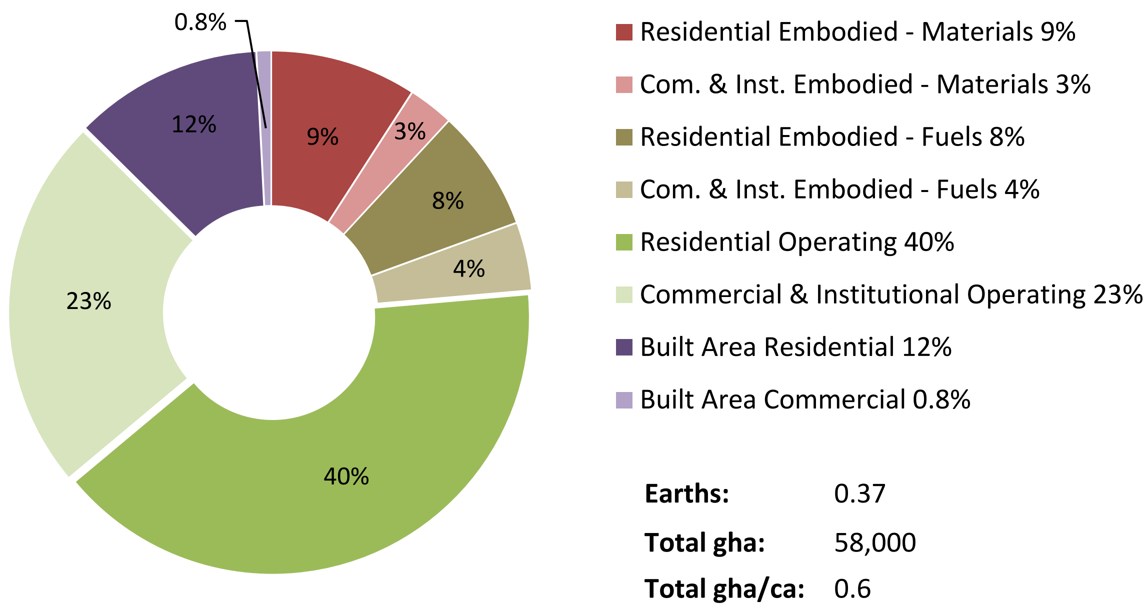


Figure 21: Ecological Footprint of Buildings for the City of Nanaimo, 2021

Ecological Footprint of Consumables and Waste

The consumables and waste EF is predominantly due to embodied impacts, with negligible contributions from built area impacts (Figure 22). Direct emissions from solid and liquid waste (which are captured in the CBEI – see Figure 13) are methane, which are not included in the EF, since typical EF methodologies only include carbon dioxide (CO2) emissions.

Embodied materials disposed (Figure 22), refer to the forest and crop areas needed to produce the disposed of materials such as paper, wood, and textiles. Embodied energy of materials disposed and recycled refers to the emissions associated with producing the materials that are disposed in landfill or recycled.

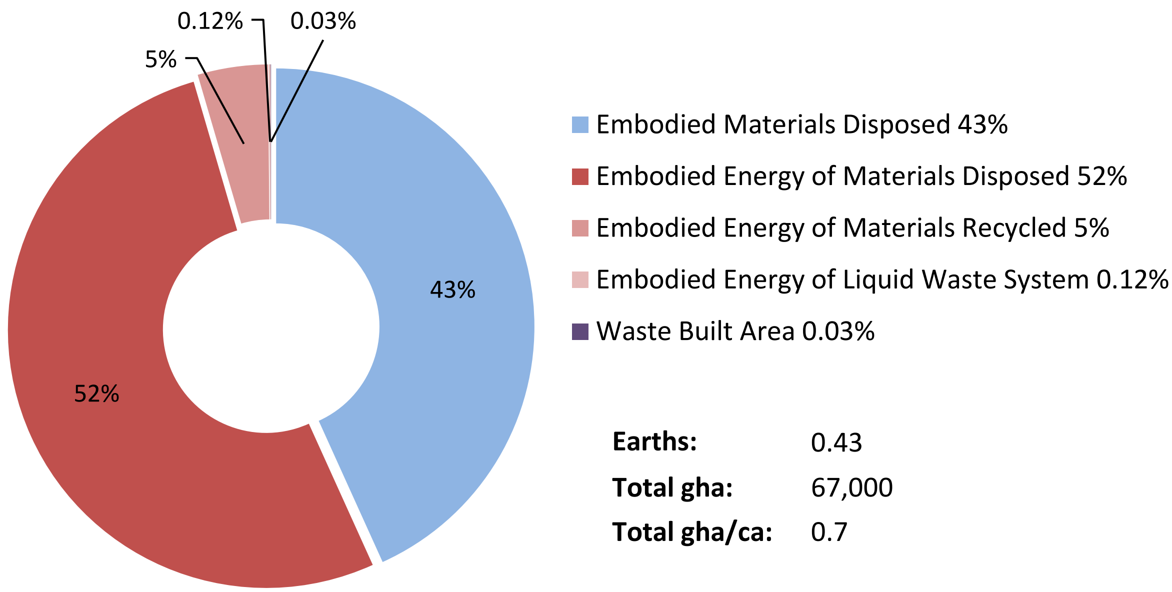


Figure 22: Ecological Footprint of Consumables & Waste for the City of Nanaimo, 2021

Figure 23 pinpoints which material streams have the greatest impact on the EF, and thus which should be prioritized for reduction. The single largest contributor to the consumables portion of the EF is non-compostable organics,[18] as is the case with the CBEI (Figure 14). Paper has a much larger impact on the EF than the CBEI due to the extensive land area needed to harvest trees, whereas plastics have a smaller impact on the EF since their production is relatively more energy intensive and less land intensive.

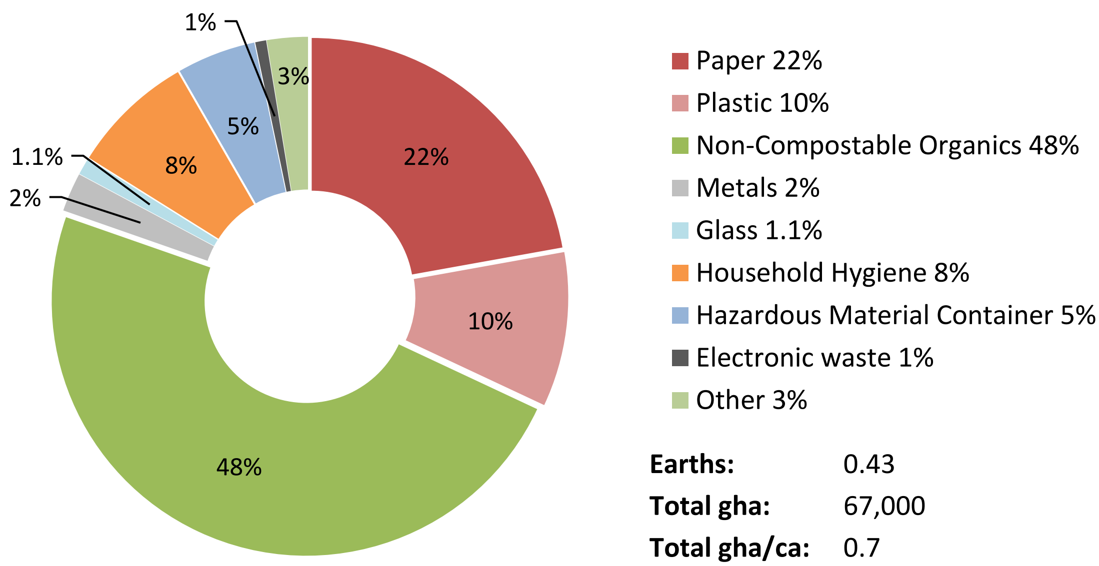


Figure 23: Ecological Footprint of Consumables & Waste by Material Type for the City of Nanaimo, 2021

[18] Non-compostable organics' includes natural fiber textiles, rubber, and non-demolition wood waste. Textiles make up approximately 90% of the impact of the non-compostable organics category.

Ecological Footprint of Transportation

The relative contributions for the EF of transportation are almost identical to the CBEI (Figure 15 to Figure 17) with a minor addition from the built area of the transportation network (Figure 24 and Figure 25).

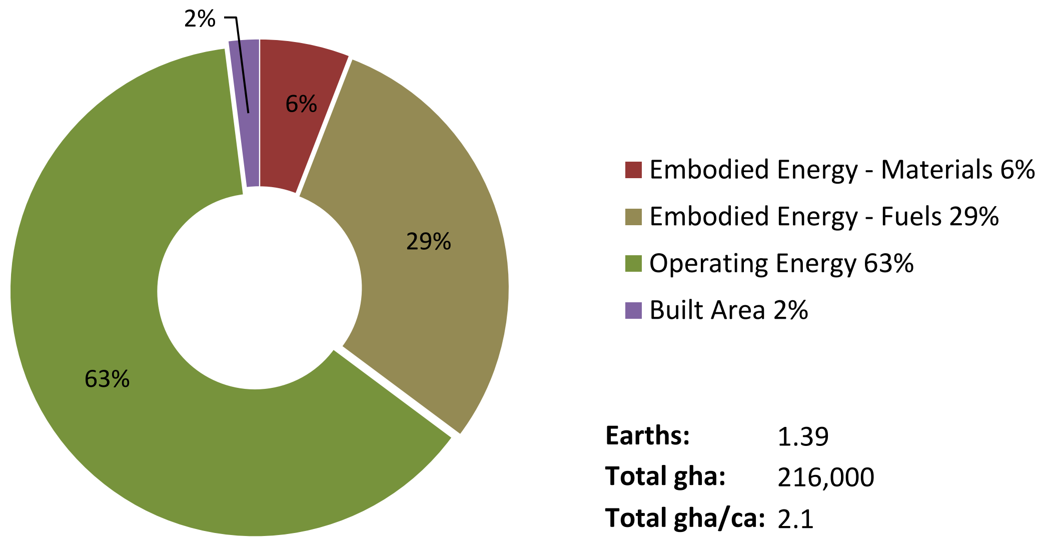


Figure 24: Ecological Footprint of Transportation for the City of Nanaimo, 2021

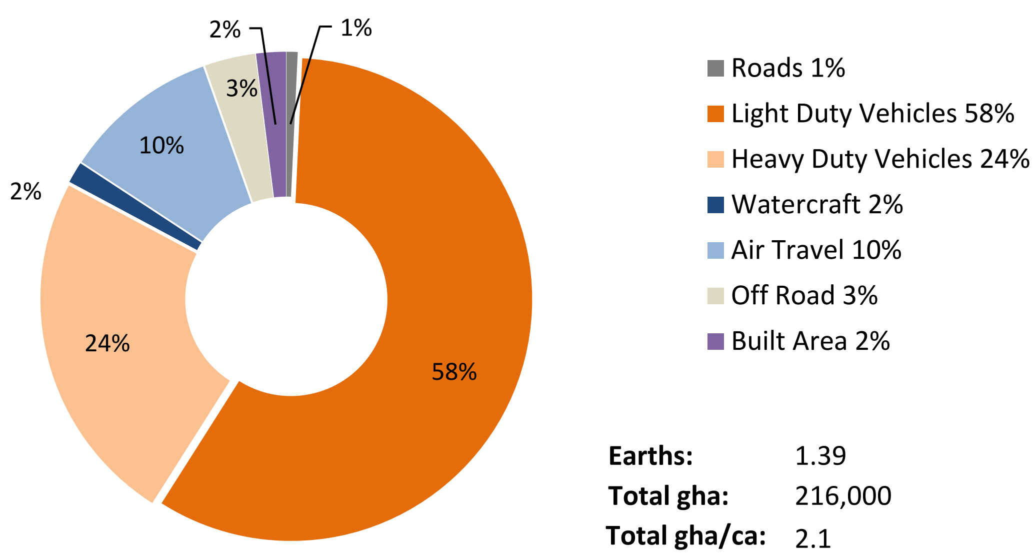


Figure 25: Ecological Footprint of Transportation by Type for the City of Nanaimo, 2021

Ecological Footprint of Water

The impacts of the fresh water supply pipes and dams has a negligible impact on the overall ecological footprint, at 0.003 Earths. This is in part due to the amortization of water supply infrastructure over its long lifespan.

Priorities for Action

The CBEI and EF identify priorities for action that are complementary to those identified by traditional sectoral inventories. An overarching priority for climate action is to minimize demand for energy and eliminate emissions from use of fossil fuels. Through a CBEI and EF lens additional opportunities for action are identified, for example:

- We can have greater impact if we go beyond switching to electric vehicles and instead focus on reducing the demand for vehicle based travel
- In addition to energy efficiency and fuel switching we will make greater gains if we reduce the material intensity of our buildings, and ensure they are used more efficiently (through right-sizing, adaptive design, adopt circular building practices)
- We can achieve dramatic reduction in our footprint and emissions if we prioritize reducing food waste across the supply chain and also shift to low carbon food choices
- And we can also pivot from emphasizing recycling and waste management to prioritizing circular opportunities that reduce consumption of raw materials

Opportunities for addressing these priorities are summarized below.

Sustainable mobility

Enabling active transportation, electrified transit and other electrified transport
- Complete compact community
- Infrastructure to enable car-free or electric car-share and bike-share

Sustainable building practices

Enabling zero and low carbon building choices
- Building efficiency, zero carbon energy sources, high density/multifamily options to minimize material use and built area, low carbon building materials

Sustainable food systems and practices

Enabling sustainable food options
- Infrastructure for low carbon, local (including urban) agriculture and gardening
- Educational campaigns to promote low carbon diets and food waste reduction

Sustainable consumption

Enabling sustainable consumption choices
- Space and infrastructure available to facilitate share/reuse/repair (circular opportunities)
- Educational campaigns to engage residents and promote sustainable lifestyles

Setting Consumption-based Emissions Targets

Whether a consumption-based, or sectoral approach is used to account for and set targets for global GHG emissions, the total global emissions are the same. The difference is just a matter of who bears the responsibility for the GHG emissions.

This means that greenhouse gas reduction targets need to be the same for consumption-based and sector-based emissions. Global emissions need to be reduced by the same amount regardless of who the emissions are allocated to. This represents a fair-share approach based on current emissions. Historical emissions are also important to consider when setting targets, as some nations, including Canada, have been responsible for much higher levels of emissions over time. Targets based on local consumption should thus be considered a minimum contribution from a fair share approach.

Science-based GHG reduction targets should be reviewed regularly to keep up to date with the latest findings, for example:

- The recent IPCC AR6 Synthesis Report, Climate Change (2023), states: "pathways that limit warming to 1.5C (>50%)[19] with no or limited overshoot reach net zero CO_2 in the early 2050s, followed by net negative CO_2 emissions".
- Studies show we are already at risk of having passed several climate tipping points and by 1.5C rise, the risk, and the number of tipping points which could be exceeded, increases (e.g. Armstrong McKay et al, Science, 2022).

In summary, even though there is growing evidence of a high risk of climate tipping points being exceeded near 1.5C of warming (or below), the most aggressive GHG mitigation pathways currently proposed by the IPCC will have a significant risk of exceeding 1.5C of warming (the 'greater than 50%' likelihood threshold is low). As the 'likelihood of limiting warming to 1.5C' is raised to a level appropriate for the potential risk, there is no remaining carbon budget to stay below 1.5C.[20,21]

Therefore, aggressive GHG reduction targets are recommended: aimed at becoming net zero as soon as possible, and beyond that, plan and set targets to become net negative (carbon dioxide removal).

[19] Includes modelled scenarios that limit warming to 1.5C in 2100 with a likelihood of greater than 50% and reach or exceed warming of 1.5°C during the 21st century with a likelihood of 67% or less. See Box SMP.1 in the report Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.
[20] See Table SPM.2 in the report Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.
[21] For a more detailed explanation please refer to the report: Consumption-based Targets, Carbon Budgets, & Our Progress to Net Zero

Appendix A: Methodology and Sources

The following provides a detailed summary of the methodology, assumptions and sources utilized in creating Nanaimo's consumption-based inventory. 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

Population

Population estimates are from Nanaimo's 2021 GPC Basic+ GHG emission inventory and Statistics Canada 2021 census.

Sources

2021 GPC Basic+ Community Greenhouse Gas (GHG) Emissions Inventory provided by staff

Statistics Canada. (2023). Focus on Geography Series*, 2021 Census*. Retrieved from https://www12.statcan.gc.ca/census-recensement/2021/dp-pd/prof/index.cfm?Lang=E

Food

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

Embodied Energy [Food Production]

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.foodemissions.com/Faq#q4

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.

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.

A local food survey was completed and used for Galiano Island's inventory. The consumption of legumes is higher and consumption of meat lower than national averages – it is assumed to be an outlier community in terms of differences in food consumption from the national average. Even with these differences emissions from food are only about 15% lower than the national average. Given this, it is assumed that the national average will be representative for Nanaimo.

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.

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

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

Embodied Energy of Fuels [Food Miles]

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

Liquid Fuels

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

Challenges and Opportunities

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

Sources

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

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

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

Distance Calculations

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

Percent Imports by Destination

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

Average Food-Miles

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

Percent Scale for Imports

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

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.

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

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

Operating Energy [Domestic Food-Miles]

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

Distance Calculations

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

Weighted Average Food-Miles

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

Challenges and Opportunities

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

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

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

Sources

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

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

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

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

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

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

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

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

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

Operating Energy [Food-Miles, Combining Imported & Domestic]

Methodologies for determining average food-miles for food imported to Canada and for food transported domestically (within Canada) are different, as described above, and are combined to estimate total transport distance for each food type.

Emission Factors and Final Calculation for Food Miles

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

Sources

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

Buildings and Stationary Energy

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

Embodied Energy of Materials [Buildings and Stationary Energy]

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 65 years for wood frame buildings and 75 years for concrete/steel frame buildings, based on national averages.

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 commercial buildings. Research for commercial office buildings is published by Carbon Leadership Forum at https://carbonleadershipforum.org/office-buildings-lca/.

Sources

Gross floor area data was provided by staff

Statistics Canada. (2018). *Table: 46-10-0008-01*: Average expected useful life of new municipally owned social and affordable housing assets, by urban and rural, and population size, Infrastructure Canada. Retrieved from https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=4610000801

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

Embodied Energy of Fuels [Buildings and Stationary Energy]

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

Note that fugitive emissions of natural gas networks that are typically reported in sectoral inventories are included within the factors for embodied emissions of fuels used in the consumption-based inventory.

Natural Gas

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

Liquid Fuels

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

Challenges and Opportunities

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

Sources

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

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

Operating Energy [Buildings and Stationary Energy]

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. Data was provided by staff from the 2021 GPC Basic+ Community Greenhouse Gas (GHG) Emissions Inventory. BC Hydro's estimated transmission loss rate of 6.3% was applied to account for emissions associated with electricity transmission losses.

Production & Consumption of Halocarbons, SF6 and NF3 [Buildings and Stationary Energy]

Emissions from production and consumption of halocarbons, SF6 and NF3 (e.g. refrigerants, foams, aerosol cans, etc.) were provided by staff from the 2021 GPC Basic+ Community Greenhouse Gas (GHG) Emissions Inventory.

Challenges and Opportunities

Emissions from refrigerants, foams and aerosol cans are estimated by the provincial and include industrial use which should not all be included in a consumption-based inventory.

Sources

2021 GPC Basic+ Community Greenhouse Gas (GHG) Emissions Inventory provided by staff

Consumables and Waste

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

Data is collected on:

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

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

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 RDN 2022 Waste Composition Study contains the total tonnage for the region and the breakdown of waste by source type (single and multi-family residential, demolition, ICI) as well as by material type. The single-family tonnage for 2023 was provided by RDN staff and used in this analysis. It is similar to the value reported in the RDN 2022 Waste Composition Study but is further disaggregated such that Nanaimo's contribution is shown.

Residential and commercial recycling tonnages and composition data are scaled from Metro Vancouver 2015 data by population as a proxy (Recycling and Solid Waste Management - 2015 Report). Local Nanaimo data only tracks a portion of residential recycling.

Direct emissions associated with landfill, waste-to-energy, and composting facilities were obtained from data provided by staff from the 2021 GPC Basic+ Community Greenhouse Gas (GHG) Emissions Inventory.

The embodied emissions of materials disposed and recycled, meaning the emissions associated with the supply chains of consumable goods (production and shipping), are estimated using lifecycle assessment data combined with the tonnage of each material type disposed. Lifecycle assessment data was compiled as part of Dr. Moore's PhD research by a research assistant, and subsequently published (Kissinger et al. 2013a; Kissinger et al. 2013b). The GHG factors were derived from literature. Material tonnages are estimated from total solid waste tonnage and the waste composition found in the RDN 2022 Waste Composition Study.

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 provided by staff from the 2021 GPC Basic+ Community Greenhouse Gas (GHG) Emissions Inventory.

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). Derived emission factors were applied to data provided by staff.

Challenges and Opportunities

Currently Nanaimo tracks only a portion of residential recycling. This could be expanded in the future to include all residential and commercial recycling which would eliminate the need for using proxy data.

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 inventory 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 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). Further research will need to be done to add additional factors.

Sources

Data provided by staff from RDN 2022 Waste Composition Study

Data provided by staff from 2021 GPC Basic+ Community Greenhouse Gas (GHG) Emissions Inventory

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)

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]

Embodied emissions of materials used for roadways, on-road vehicles, ferries, and aircraft are included.

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

Factors for calculating embodied emissions of on-road vehicle materials are available in LCA literature. Averages of factors in several LCA studies were used for each vehicle type. Vehicle data was provided by staff from the 2021 GPC Basic+ Community Greenhouse Gas (GHG) Emissions Inventory.

There are few LCA studies for specific marine vessels. For ferries, average factors in "tCO2e/tonne steel" were applied.

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

Challenges and Opportunities

Estimates of embodied emissions of materials for off road vehicles and equipment, and other infrastructure are not included in the inventory.

Sources

Lane kilometers provided by staff

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

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

2021 GPC Basic+ Community Greenhouse Gas (GHG) Emissions Inventory provided by staff

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

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

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

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

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

Embodied Energy of Fuels [Transportation]

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

Operating Energy [Transportation] Road, Off-road and Marine

Emissions data was provided by staff from the 2021 GPC Basic+ Community Greenhouse Gas (GHG) Emissions Inventory.

Sources

2021 GPC Basic+ Community Greenhouse Gas (GHG) Emissions Inventory provided by staff

Operating Energy [Transportation] Air Travel

Air travel emissions were estimated using the National Energy Use Database (NEUD) for 2019 (latest year at time of inventory) allocated on a per-capita basis.

Challenges and Opportunities

Comparison of the NEUD data to air travel studies (comprehensive analysis of YVR traffic) suggests that it provides a reasonable approximation of a community's total air travel impact (including out-of-boundary travel).

In the future local data could be gathered through a travel survey. This was done for an inventory of Galiano Island air travel.

Sources

Natural Resources Canada. (n.d.). National Energy Use Database. Retrieved from https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive_tables/list.cfm

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]

Concrete used in dams and pipe lengths were provided by staff and regional reports.

Sources

Data provided by 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

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