EXTENDED ABSTRACT

Consequential Greenhouse Gas Emissions from Household Travel in Vancouver, Canada

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1 Introduction

Transportation contributes roughly one third of greenhouse gas (GHG) emissions in Canada, with the majority associated with passenger travel. Despite decades of efforts to reduce motor vehicle emissions through efficiency gains, steady increases in the quantity of travel have led to a net increase in GHG emissions from the transportation sector. New and more effective strategies are needed, which requires accurate understanding of how various factors influence the climate impacts of passenger travel.

This study aims to generate the first estimates of consequential daily GHG emissions from personal travel (Bigazzi, Forthcoming), and examine its associations with household and contextual factors. To determine the importance of the carbon accounting framework, we also investigate differences in daily GHG emissions (for persons and households) estimated by consequential versus attributional methods. In addition to these research objectives, the results of this analysis were applied in a broader study on the joint health and climate impacts of the built environment (Frank et al., 2024).

2 Methods

Key components of the modelling framework are illustrated in Figure 1. Three main local data sources for the Vancouver, Canada metropolitan area are used in the emissions estimates: household travel survey (HTS) data, road network data from the regional travel model (RTM), and transit system operations data. Automobile and transit emission rates are generated from MOVES modelling (U.S. Environmental Protection Agency, 2022) and transit system operations data, respectively. Operating automobile and transit emissions are calculated by applying vehicle-and route-specific emission rates to observed trips in the HTS. Fuel efficiency data from Natural Resources Canada (NRCAN) (2022) are used to adjust automobile emission rates for variation by vehicle make and model within the MOVES vehicle type categories. Vehicle operating emissions are augmented with upstream emissions for fuel and vehicle life cycle estimates, and then attributed to vehicle occupants to generate attributional trip emissions. A marginal adjustment is then applied to generate consequential trip emissions (Bigazzi, 2019). Finally, trip emissions are aggregated up to the person and household for relational analysis.

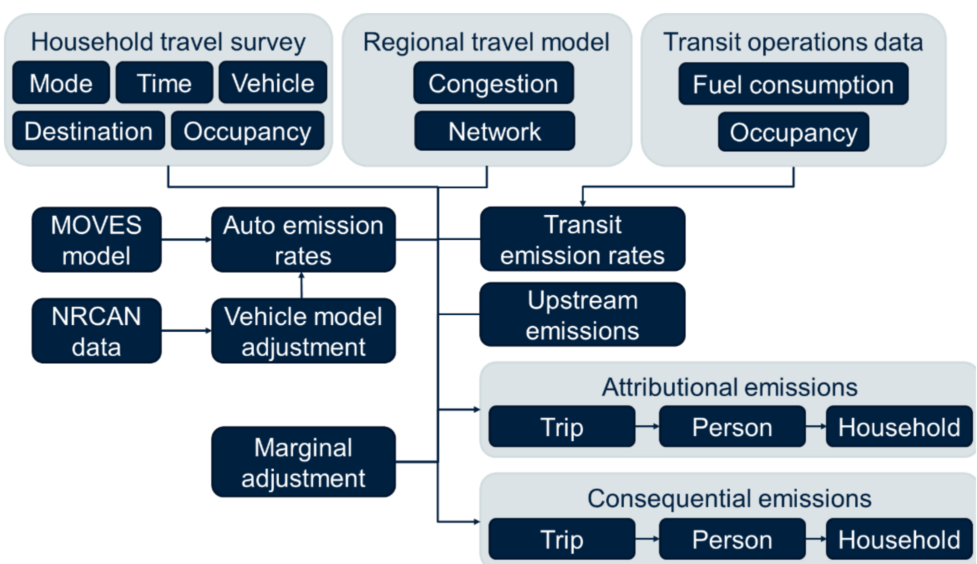

Figure 1. Emissions modelling framework

Weighted log-linear mixed effects regression modelling is used to investigate associations between estimated emissions from travel (in mass per person per day) and household and environmental variables including household composition and demographics, vehicle availability, and walkability. Random effects for household are specified to account for the hierarchical nature of the travel data (travel by persons within households).

3 Results

Overall in the sample, automobile trips accounted for 79% of person-kilometers travelled (PKT) and 97% of attributional GHG emissions; transit bus trip segments contributed another 2% of emissions with 7% of PKT, and all other modes combined contributed less than 1% of GHG emissions but 14% of PKT. Operating phases accounted for 59% of total GHG emissions (56% running + 3% start) and non-operating phases accounted for the other 41% (22% well-to-tank fuel cycle + 20% vehicle cycle). Figure 2 gives the average GHG emissions intensity per PKT by primary mode of each trip. These values aggregate the emissions by trip, so even if the primary mode has no operating emissions (e.g., SkyTrain rapid rail), access by automobile would generate operating emissions for the trip.

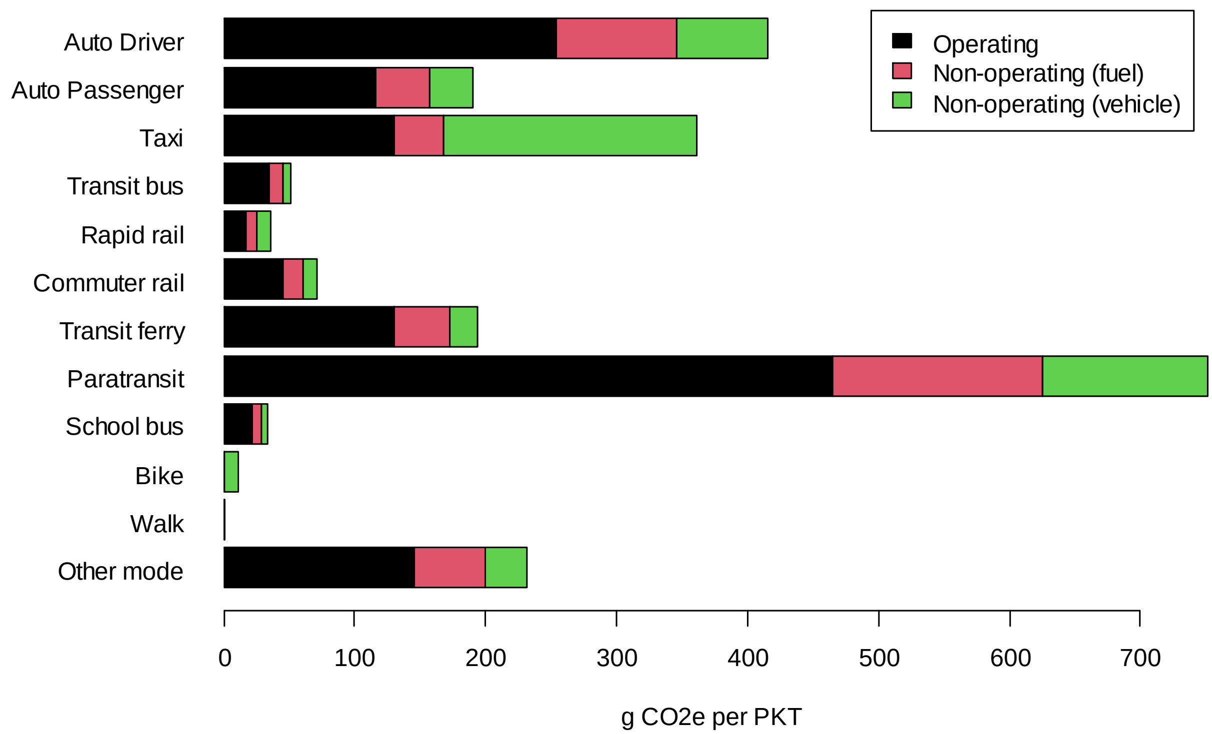

Figure 2. Average emissions intensity per PKT by primary mode of trip

Table 1 reports summary statistics for PKT and emissions aggregated up to the person and household using sampling weights. Emissions vary widely across people and households, with interquartile ranges larger than mean values. The 75th percentile households are generating 7 times the daily emissions of 25th percentile households; 75th percentile persons are generating more than 40 times the daily emissions of 25th percentile persons. Some of this is due to higher PKT, which varies by a factor of 5 and 9 over the interquartile range of households and persons, respectively, but emissions intensity (g CO_2e per PKT) also varies by a factor of 2 to 4 over the interquartile range. Consequential emissions are lower than attributional emissions and also vary more widely across people and households, with interquartile ranges (difference between 75th and 25th percentiles) proportionally larger than median values compared to attributional emissions.

Table 1. Person- and household-level (weighted) PKT and GHG

	Person-level				Household-level			
Measure	1st Qrt[1]	Median	Mean	3rd Qrt	1st Qrt	Median	Mean	3rd Qrt
Daily PKT	5.42	21.22	36.91	49.16	25.42	61.81	91.39	121.22
Daily attributional GHG[2]	0.30	3.90	10.21	13.27	5.04	16.18	25.28	34.41
Daily consequential GHG[2]	0.26	3.53	9.29	12.04	4.55	14.64	23.01	31.37
Attributional GHG intensity[3]	93	236	252	383	165	285	277	385
Consequential GHG intensity[3]	82	209	229	349	146	254	252	351

[1] Quartile

[2] In kg CO_2e

[3] In g CO_2e per PKT; excludes persons or households with no travel

3.1 Relationships with household and factors

Living in more walkable areas was associated with reduced emissions: people living in the 20% least walkable quintile of neighbourhoods averaged 16 kg/day in GHG emissions (CO_2e) from travel, while those in the 20% most walkable quintile of neighbourhoods averaged 3 kg/day, with the intervening quintiles laddering down in 3-5 kg/day intervals. At the household level, daily GHG emissions fell from 30 to 5 kg/day for the least versus most walkable neighbourhood quintiles. Lower GHG correspond with reduced auto usage and increasing transit and active travel, as expected.

The estimated GHG regression model has marginal and conditional R^2 values of 0.35 and 0.54, respectively. Regression model results reveal a graded relationship across walkability bins for GHG emissions, with each increase in walkability quintile associated with significant reductions in GHG emissions of 10% to 30%. These effects persist after controlling for a range of personal and household characteristics such as age, gender, income, employment status, and vehicle ownership. The results for consequential CO_2e emissions are similar to those for attributional CO_2e emissions, although sensitivity varies for some factors. The effects of income, employment status, and vehicle availability are larger for consequential than attributional emissions, while the effects of walkability and gender are smaller.

4 Discussion and Conclusions

Two particularly novel aspects of our methodology are 1) applying a vehicle-make adjustment to the MOVES-modelled emissions rates, to account for both congestion effects on emissions and sub-vehicle-class variation in fuel efficiency, and 2) accounting for dynamic transit vehicle occupancy by line, direction, day, and hour. Our approach, in contrast to the more common method of using fixed per-PKT emission rates by mode, reveals highly dynamic intra-modal emissions intensity. This sensitivity to trip and traveller attributes beyond trip distance and mode is important for the subsequent analysis of the factors that influence emissions from household travel.

Travel-related emissions in metropolitan Vancouver are primarily generated by private automobile use, which is greatly curtailed in more walkable parts of the region. Higher levels of walkability are associated with increased walking and transit use, and fewer motor vehicle trips, which leads to lower travel-related emissions. The statistical analysis results are consistent with previous findings in other locations which tend to report that both individual and neighbourhood factors are associated with the emissions generated for daily travel purposes (Darwish et al., 2023; Frank et al., 2000; Rickwood et al., 2008; Steemers, 2003; Wang et al., 2023; Wu et al., 2019). Other results are also supported by past research, which reported similar relationships between individual attributes and emissions, including that higher income households tend to produce more travel-related emissions (Barla et al., 2011; Brand and Preston, 2010; Kahn, 1998; Ko et al., 2011; Sider et al., 2013).

To our knowledge this is the first study to apply a consequential accounting framework to estimate the climate impacts of household travel. By reporting both attributional and consequential values, the results provide insights into the bias that can result from application of an inappropriate framework. The estimated emissions calculated using attributional versus consequential accounting frameworks are similar but have different relationships with personal, household, and environmental factors. The effect of accounting framework is largest for transit trips, and greater for households with less automobile use, which tend to have lower incomes. Hence, the selection of carbon accounting framework has equity implications for the analysis results. We hope that this study provides momentum toward greater attention to carbon accounting frameworks in transportation analyses, and spurs further research on the marginal impacts of passenger trips on total system emissions.

5 References

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