BC COMMUNITY ENERGY EMISSIONS INVENTORY (CEEI) DECOMPOSITION ANALYSIS

A Methodological Exploration

Prepared by

Robert Newell

Meeting the Climate Change Challenge (MC^3)

Royal Roads University

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www.mc-3.ca

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1. INTRODUCTION

In 2007, the BC Government developed the Climate Action Charter to promote a concerted effort between local and provincial governments toward addressing climate change. As part of this effort, municipalities have committed to measuring greenhouse gas (GHG) emissions in regular intervals, and such data has been collected and compiled into the BC Community Energy Emissions Inventory (CEEI). This has resulted in a rich dataset that captures GHG emissions for multiple years, by various sectors, and from different communities; however, the question remains – how do we best use this data to inform policy and decision-making toward climate action?

Decomposition analysis provides a potentially powerful means for achieving this objective. This form of analysis can be used to breakdown and examine factors that influence changes in GHG emissions over a given period of time. Through decomposition, we can uncover what is contributing to increases in GHG emissions and driving climate change, as well as understanding where we are making progress in reducing emissions. Factors such as changes in the types of cars people drive and changes in how much people drive (e.g., average trip length) can be isolated, and these changes can be examined to see whether they have led to either increases or decreases in greenhouse gases. With this information, the appropriate inventions can be made to address the areas where GHG emissions are increasing, whether this be done through policies, land-use planning, financial tools, and/or educational campaigns.

The Meeting the Climate Change Challenge (MC^3) project explores this analytical potential by developing decomposition models that can interrogate CEEI data in order to produce insights on priority areas for climate action. Models have been created for transportation, residential, and commercial/industrial sectors, and factors within these sectors are examined for whether they have contributed to increases or decreases in GHG emissions between 2007 and 2012. Unlike other studies that employ decomposition methodology (e.g., Jian, 2015; Lv et al., 2014; Xu et al., 2006), MC^3 takes a unique approach by focusing on smaller scales (i.e., local regions rather than province/state or nation), and by doing so, we aim to develop a method that can aid local governments in moving toward sustainable development pathways.

The following report describes preliminary work that explores ways of applying decomposition methodology to CEEI data (collected for the years 2007, 2010 and 2012). It is important to note that this report primarily concerns methodology; thus, it focuses on the insights gained from developing decomposition approaches for and applying analyses to community level data. Interpretations around the results are reserved for forthcoming publications.

This research is part of the MC^3 project, which is a research effort led by Professors Ann Dale, Royal Roads University, and John Robinson, University of Toronto. I am indebted to the intellectual contributions of Professor John Robinson to the development of this work.

1.1 Objectives

The objectives of this work are four-fold.

1. **Making use of CEEI data**. As noted above, municipal signatories to the Climate Action Charter have committed to reducing their GHG emissions, and as part of this commitment, signatories inventory their GHG emissions. The decomposition analyses conducted in this research were applied to CEEI data in order to see how this type of analysis could support the goals of the Charter and CEEI, by providing finer grain information that would allow communities to better determine whether they are actually reducing GHGs and which areas require more attention in achieving concrete GHG reductions

2. **Allowing for ongoing analyses**. Ensuring that GHG emissions reach and are maintained at certain targets requires continual monitoring. This means that analysis cannot occur as a single 'snapshot' in time; rather, it must be designed as process that can continually be applied. However, for the process to be continual, the appropriate data must be available; that is, data that is consistent in terms of what is measured (and how it is measured) year over year. The analysis described here primarily uses only variables and measures obtained through the CEEI in order to use an inventorying process that is (relatively) consistent from year to year and thus can be 're-applied' as new years of data are collected.

3. **Examining GHG emissions at the sub-provincial level**. Many decomposition analyses are conducted at larger geographical scales, such as at the national level (e.g., Jian, 2015; Lv et al., 2014; Xu et al., 2006); however, the Climate Action Charter and CEEI were implemented to spur local government action. Accordingly, the analyses in this work are conducted at sub-provincial levels. However, for most of the analyses, the scale selected is regional rather than individual local governments due to the fact that vicinal communities are often intimately inter-linked, and thus so are their emissions. For example, the local governments within the Capital Regional District (CRD) will have people that frequently travel across municipal borders for work, recreation, and to access services and amenities.

4. **Understanding GHG emissions in terms of human activities and lifestyles**. The analyses in this work focus specifically on the behaviours, lifestyles and needs of the people living within BC communities. As noted above, the analyses are conducted at a sub-provincial level; therefore, they are designed to capture insights that would be useful for community planners and decision-makers (such as decomposition of travel behaviours), rather than insights that would be more appropriate for provincial or federal decision-makers (such as decomposition of macro-level economics and/or resource industries).

2. DECOMPOSITION METHOD

Decomposition analysis disaggregates different factors that influence changes in a specific variable or subject of interest (E). Factors present in a basic decomposition formula include activity (A), structure (S) and intensity (I). Activity refers to the magnitude of an action that influences E, structure refers to the composition of different elements related to the actions influencing E, and intensity refers to strength in which elements and actions are exerting an effect on E.

Equation 1. $E = \sum A * S_i * I_i$

The effects each of the factors has on E can be calculated through different decomposition methods. In this research, calculations were based on additive formulae of the Logarithmic Divisia Index (LMDI) and followed methodology presented by Ang (2012) and Heinen (2013). Accordingly, individual factor effects were measured through formulae following this form.

Equation 2. $[\text{Activity Effect}] = \sum L(E_i^T, E_i^0) * ln(A_i^T / A_i^0)$

Equation 3. $[\text{Structure Effect}] = \sum L(E_i^T, E_i^0) * ln(S_i^T / S_i^0)$

Equation 4. $[\text{Intensity Effect}] = \sum L(E_i^T, E_i^0) * ln(I_i^T / I_i^0)$

The first attempts at decomposing CEEI data (done in August/September of 2015) employed the basic decomposition formula displayed above and consisted of three factors, A, S, and I. However, doing this did not allow for a comprehensive use of the CEEI data set and did not produce rich insights. To remedy this, the current analyses employ formulae that include more than three factors, similar to that described in (Ang, 2012; Jiang, 2015), resulting in decomposition models with multiple structural and intensity factors. These analyses accommodate a wider range of variables, allowing for a more thorough exploration of contributors to GHG emissions.

It is important to note that decomposition formulae must be designed so that factors disaggregate properly and units/measures 'agree' with one another. This means that if (for example) community population is a numerator in one factor, then it needs to be a denominator in another. Such a consideration guides how the formulae are designed, and it requires composing factors in particular numerator-denominator relationships to allow for certain variables to be included.

2.1 Figures

Throughout this report, two types of graphs commonly appear. The first displays total values of effects on GHG emissions for a region. This type of graph is relatively straightforward in that it simply reports the additive values produced from each of the effects formulae applied to the data.

The second type of graph displays signed proportionate values for each of the regions. This type of graph features bars that span a value of 1 on the y-axis, representing the full range of summed negative to summed positive effects. The bars then are divided into the proportionate positive or negative amounts, according to how much of the total a particular variable assumes. Because these graphs are comprised of assigned proportionate values, a bar that spans above 0.5 on the y-axis could be considered as consisting of net positive cumulative effects and a bar that spans below -0.5 on the y-axis could be considered as consisting of net negative cumulative effects.

3. DECOMPOSITION ANALYSES

3.1 Transportation Factors

This decomposition examines transportation behaviour, and it provides insights on how factors related to people's movement within communities/regions influence GHG emissions. Transportation decomposition analysis only uses data from 2007 and 2010 because 2012 data is not available for certain regions.

The transportation decomposition model contains five factors. Respectively, the factors serve to provide insight on how many people or 'potential travellers' exist within a region, where people are living (e.g., in Vancouver proper or adjacent communities), the amount people are driving, the types of vehicles people are driving, and the efficiency of the vehicles. A more detailed description of these factors can be seen below.

Equation 5. $E = \sum P * R_i * U_i * S_{ij} * I_{ij}$

Equation 6. $[Emissions] = \sum [Population] * ([Population]_i / [Population]) * ([VKT]_i / [Population]_i) * ([VKT]_{ij} / [VKT]_i) * ([Emissions]_{ij} / [VKT]_{ij})$

3.1.1 *Descriptions of Factors*

Emissions (E) is the variable or item of interest, and it is measured in kilotonnes of CO_2 equivalent.

Population (P) captures changes in total population within a region. Population effects in this analysis refer to how many potential motorists (i.e., people) are present in the region. Although BC's population did not change dramatically between 2007 and 2010, this factor was considered important to include for two reasons. Firstly, this method is designed for ongoing analyses, and population dynamics might exert more of an effect in the future. Secondly, the analysis is done for different sub-provincial regions, and each of these regions experience different levels of growth or (in some cases) population decreases.

Regional population structure (R) is a structural factor that captures population share among different communities within a region. Population structural effects provide insights on how increases in urban density might influence vehicle-related emissions.

Travel intensity (U) is an intensity factor that captures the amount of kilometers travelled per person. Travel intensity effects relate to whether people are travelling more or less using fossil fuel based vehicles.

Vehicle type structure (S) is a structural factor that captures the composition of kilometers travelled by different types of vehicles. Types (or categories) of vehicles are defined through the CEEI as small passenger cars, large passenger cars, light trucks/vans/SUVs, motorhomes, motorcycles/mopeds, and bus. Vehicle structural effects provide insight on how 'shifts' in usage of different types of vehicles can influence GHG emission levels.

Emissions intensity (I) captures the GHG emissions produced travelling certain distances, and it is linked to fuel economy. CEEI calculations account for increases in fuel efficiency in cars over the years, as well as increasing/decreasing usage of more fuel efficient types of cars (e.g., hybrids).

3.1.2 *Formulae for Factor Effects*

Factor effects provide insights on how each of the factors influence changes in GHG emission. These effects are calculated through the following formulae.

Equation 7. [Population Effect] = $\sum L(E_i^T, E_i^0) * ln(P_i^T / P_i^0)$

Equation 8. [Regional Population Structure Effect] = $\sum L(E_i^T, E_i^0) * ln(R_i^T / R_i^0)$

Equation 9. [Travel Intensity Effect] = $\sum L(E_i^T, E_i^0) * ln(U_i^T / U_i^0)$

Equation 10. [Vehicle Type Structure Effect] = $\sum L(E_i^T, E_i^0) * ln(S_i^T / S_i^0)$

Equation 11. [Energy Intensity Effect] = $\sum L(E_i^T, E_i^0) * ln(I_i^T / I_i^0)$

* Where $L(a , b) = (a – b) / ln(a / b)$ for $a \neq b$
When a=b, $L(a , b) = 0$ (Torrie et al., n.d.)
And, small value strategy ($\delta=10^{-100}$) for zero values (Ang and Liu, 2007)

3.1.3 *Results*

As mentioned in *1. Introduction*, this report primarily focuses on methodology and does not provide in depth interpretations of the output of the analyses. However, the report does provide brief descriptions of the findings to illustrate how the output can be interpreted. In the case of the transportation analysis, the following trends can be seen.

- Decreases in GHG emissions were mostly due to increases in efficiency (i.e., energy intensity effects) and fuel/energy types (i.e., conversion factor).

- Increases in Metro-Vancouver's population exerted the largest positive effect on GHG emissions; however, this was offset by energy intensity effects experienced in the region.
- Travel intensity effects positively influenced GHG emissions in all regions except the Capital Regional District, Fraser Valley, Fraser-Fort George, and Metro-Vancouver.
- Vehicle structure effects positively influenced GHG emissions in all regions except Comox Valley, Mount Waddington, Skeena-Queen Charlotte, and Strathcona.

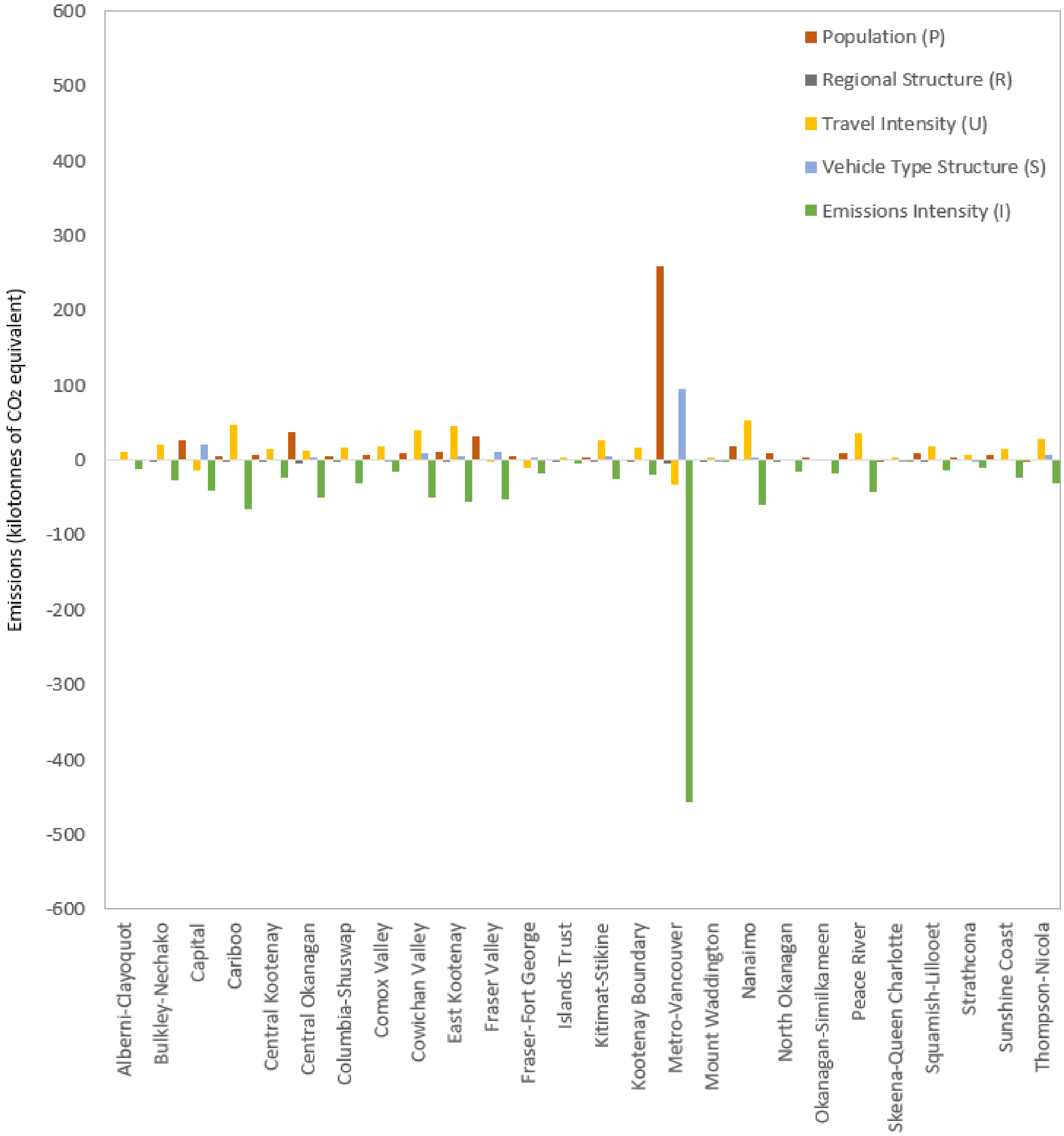

Figure 1. *Decomposition of vehicle-related factor effects on GHG emissions for different BC regions*

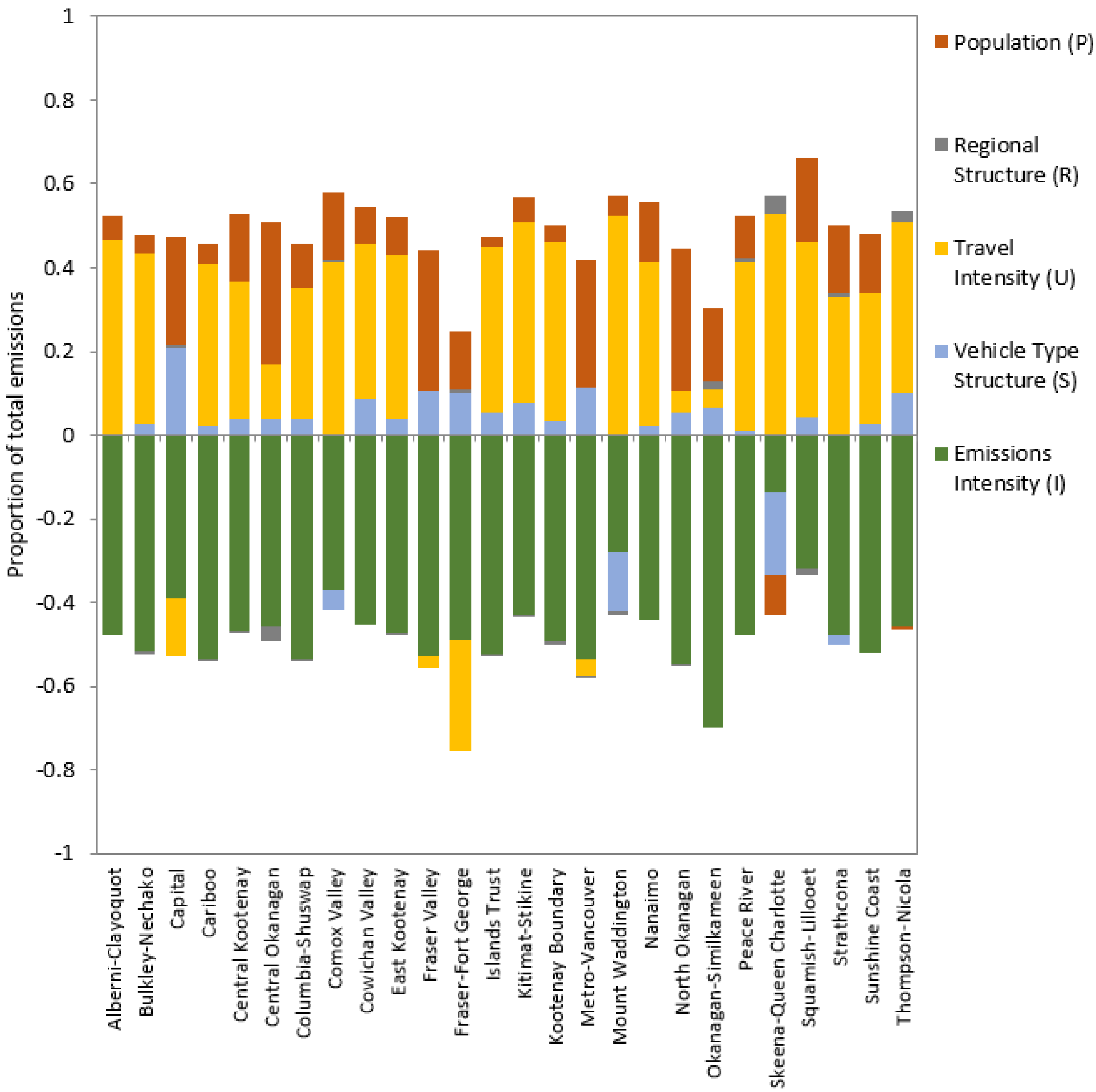

Figure 2. *Proportionate values of vehicle-related factor effects on GHG emissions for different BC regions*

3.2 Residential Factors

This decomposition explores residential energy use, and it provides insights on how factors relating to personal home energy consumption influence GHG emissions. Data for 2012 was not available for the Island Trust Area; thus, this region is excluded from the analysis.

The residence decomposition model contains five factors. Respectively, the factors serve to provide insight on how many residents exist within a region, where people are living (i.e., in communities of high or low urban density), the degree to which people are sharing living spaces (i.e., by looking at utility accounts per capita), the sources of energy for heating living spaces, and how efficient residential buildings are in terms of heating and emissions. A more detailed description of these factors can be seen below.

Equation 12. $E = \sum P * R_i * U_i * S_{ij} * I_{ij}$

Equation 13. $[Emissions] = \sum [Population] * ([Population]_i / [Population]) * ([Connections]_i / [Population]_i) * ([Connections]_{ij} / [Connections]_i) * ([Emissions]_{ij} / [Connections]_{ij})$

3.2.1 *Descriptions of Factors*

Emissions (E) is the subject of interest, and it is measured in kilotonnes of CO_2 equivalent.

Population (P) captures changes in total population in a region. Population effects in this analysis refer to how many home energy consumers (i.e., people) reside in the region. This factor was considered important for the analysis for the same reasons as stated in the transportation analysis above.

Regional population structure (R) is a structural factor that captures population share among different communities within a region. Population structural effects provide insights on how increases (or decreases) in urban density might affect home energy usage; for example, increases in urban dwelling types such as apartments can result in lower heating energy requirements.

Connections intensity (U) is an intensity factor that captures the ratio of utility accounts (i.e., connections) to people. Effects of this factor provide insights on how co-habitation (or lack thereof) influences residential energy usage and (consequently) GHG emissions.

Energy type structure (S) is a structural factor that captures share of energy consumption by source or fuel type. This analysis is somewhat limited in that data is only available for electricity and natural gas; however, the analysis does provide insights around shifts between electric and gas-based heating.

Emissions intensity (I) is an intensity factor that captures GHG emissions per connection. Effects of this factor provide insight on the emissions per energy account, i.e., household.

3.2.2 *Formulae for Factor Effects*

Factor effects illustrate how each of the residential factors influence changes in GHG emissions. They are calculated through the following formulae.

Equation 14. [Population Effect] = $\sum L(E_i^T, E_i^0) * ln(P_i^T / P_i^0)$

Equation 15. [Regional Population Structure Effect] = $\sum L(E_i^T, E_i^0) * ln(R_i^T / R_i^0)$

Equation 16. [Connections Intensity Effect] = $\sum L(E_i^T, E_i^0) * ln(U_i^T / U_i^0)$

Equation 17. [Emissions Type Structure Effect] = $\sum L(E_i^T, E_i^0) * ln(S_i^T / S_i^0)$

Equation 18. [Emissions Intensity Effect] = $\sum L(E_i^T, E_i^0) * ln(I_i^T / I_i^0)$

* Where $L(a , b) = (a – b) / ln(a / b)$ for a≠b
When a=b, $L(a , b) = 0$ (Torrie et al., n.d.)
And, small value strategy ($\delta=10^{-100}$) for zero values (Ang and Liu, 2007)

3.2.3 *Results*

As this report focuses on methodology, only brief descriptions of the findings are given to illustrate how decomposition output can be interpreted. Findings from the residential analysis reveal the following patterns.

- Energy intensity effects of Metro-Vancouver had the most significant influence in terms of GHG emissions reductions; whereas, Metro-Vancouver population increase had the most significant influence in terms of emissions increases.

- Connections intensity effects negatively influenced GHG emissions in 31% of the regions. This effect appears to have a particularly significant influence in Metro-Vancouver, even though the number of connections per person has varied relatively little from 2007 to 2012 (connections per person was 0.557 in 2007, 0.545 in 2010, and 0.551 in 2012).

- Energy intensity effects negatively influenced GHG emissions in all regions.

- Energy type structure effects (i.e., electricity and natural gas composition) were mixed with positive influences on GHG emissions observed with 54% of the regions.

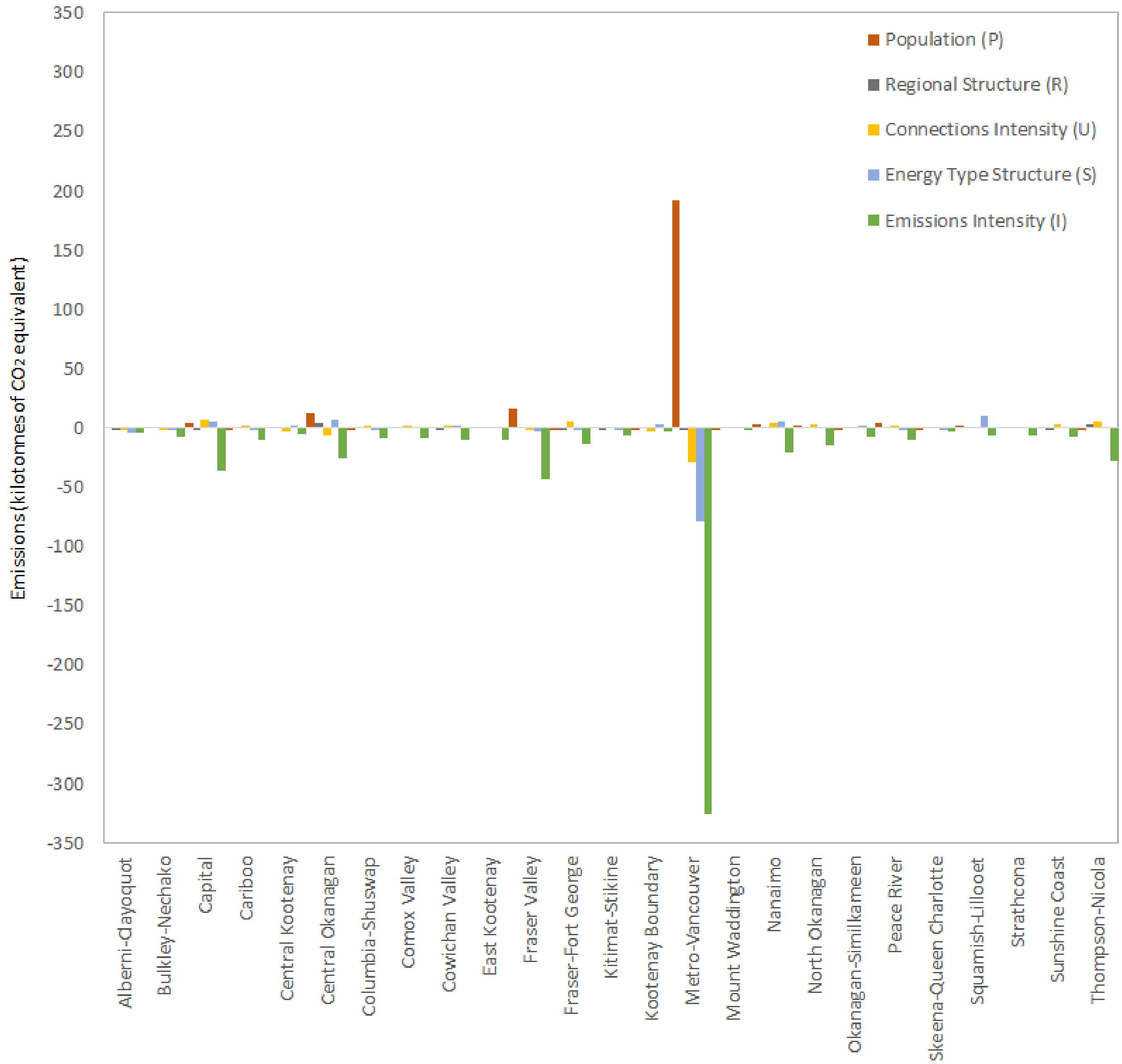

Figure 3. *Decomposition of residence-related effects on GHG emissions for different BC regions*

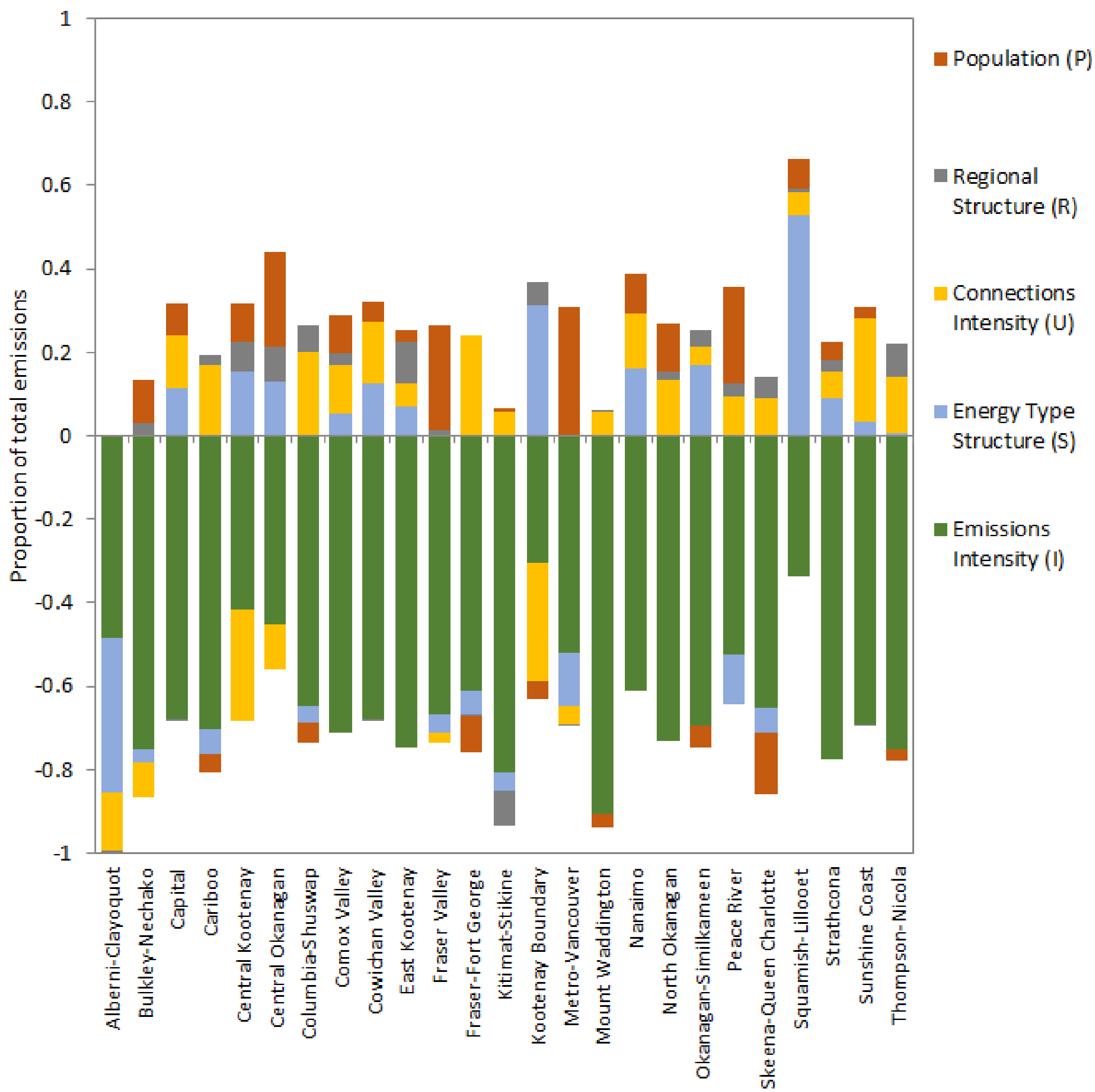

Figure 4. *Proportionate values of residence-related effects on GHG emissions for different BC regions*

3.3 Commercial and Small Industrial Operations Factors

The commercial and light-industrial sector of CEEI data refer to a collection of different operations, such as offices, commercial retail outlets, government buildings (e.g., schools and hospitals), other institutions and small to medium industrial facilities (BC Ministry of Environment, 2014). This decomposition explores the energy used by these types of operations, and insights from the analysis capture the influence amenities, services and places of work have on GHG emissions.

The commercial and light-industrial energy decomposition model contains five factors. Respectively, the factors serve to provide insight on how many people exist within a region (i.e., numbers of 'users', 'owners' and 'operators' of commercial and light-industrial facilities), where people (i.e., users, owners and operators) are living within a region, the numbers of businesses and industrial operations (estimated through utility account data) that exist per person, sources of energy for commercial and industrial operations, and how efficient these operations are in terms of energy usage and emissions production. A more detailed description of these factors can be seen below.

Equation 19. $E = \sum P * R_i * U_i * S_{ij} * I_{ij}$

Equation 20. $[\text{Emissions}] = \sum [\text{Population}] * ([\text{Population}]_i / [\text{Population}]) * ([\text{Connections}]_i / [\text{Population}]_i) * ([\text{Connections}]_{ij} / [\text{Connections}]_i) * ([\text{Emissions}]_{ij} / [\text{Connections}]_{ij})$

3.3.1 *Descriptions of Factors*

Emissions (E) - This is the subject/variable of interest, and it is measured in kilotonnes of CO_2 equivalent.

Population (P) captures changes in total population in a region. Population effects in this analysis refer to how many workers, service-users, and shoppers (i.e., people) are present in the region. This factor was considered important for the analysis for the same reasons as stated in the transportation and residence analysis.

Regional population structure (R) is a structural factor that captures population share among different communities within a region. Population structural effects provide insight on how increases (or decreases) in urban density might affect energy requirements for amenities, services and places of work.

Connections intensity (U) is an intensity factor that captures ratios of commercial/small-industrial utility accounts (i.e., connections) to people. Effects of this factor provide insight on how service, amenity and workplace sharing affects commercial/small-industrial energy usage and (consequently) GHG emissions.

Emissions type structure (S) is a structural factor that captures share of emissions production by source or fuel type. For commercial and small-industrial operations, data is available for electricity, natural gas, and propane.

Emissions intensity (I) is an intensity factor that captures GHG emissions per connection. Effects of this factor provide insight on emissions produced per energy account, i.e., commercial or small-industrial operation.

3.3.2 *Formulae for Factor Effects*

Factor effects illustrate how each of the commercial and light-industrial energy factors influence changes in GHG emission. They are calculated through the following formulae.

Equation 21. [Population Effect] = $\sum L(E_i^T, E_i^0) * ln(P_i^T / P_i^0)$

Equation 22. [Regional Population Structure Effect] = $\sum L(E_i^T, E_i^0) * ln(R_i^T / R_i^0)$

Equation 23. [Connections Intensity Effect] = $\sum L(E_i^T, E_i^0) * ln(U_i^T / U_i^0)$

Equation 24. [Energy Type Structure Effect] = $\sum L(E_i^T, E_i^0) * ln(S_i^T / S_i^0)$

Equation 25. [Energy Intensity Effect] = $\sum L(E_i^T, E_i^0) * ln(I_i^T / I_i^0)$

* Where $L(a , b) = (a – b) / ln(a / b)$ for $a \neq b$
When a=b, $L(a , b) = 0$ (Torrie et al., n.d.)
And, small value strategy ($\delta=10^{-100}$) for zero values (Ang and Liu, 2007)

3.3.3 *Results*

As this report focuses on methodology, only brief descriptions of the findings are given to illustrate how decomposition output can be interpreted. Findings from the commercial and light-industrial energy analysis reveal the following patterns.

- Increased population in Metro-Vancouver had the most significant positive influence on emissions.
- Energy type structure effects were exhibited a negative influence on GHG emissions in most of the regions, and this was observed for approximately 70% of the regions.
- Unlike the residence analysis where energy intensity effects negatively influenced GHG emissions in all regions, only 62% of the regions exhibited a negative influence with respect to this particular effect.
- Connections intensity effects exhibited a negative influence in all regions except Columbia-Shuswap, Mount Waddington, and Thompson-Nicola.

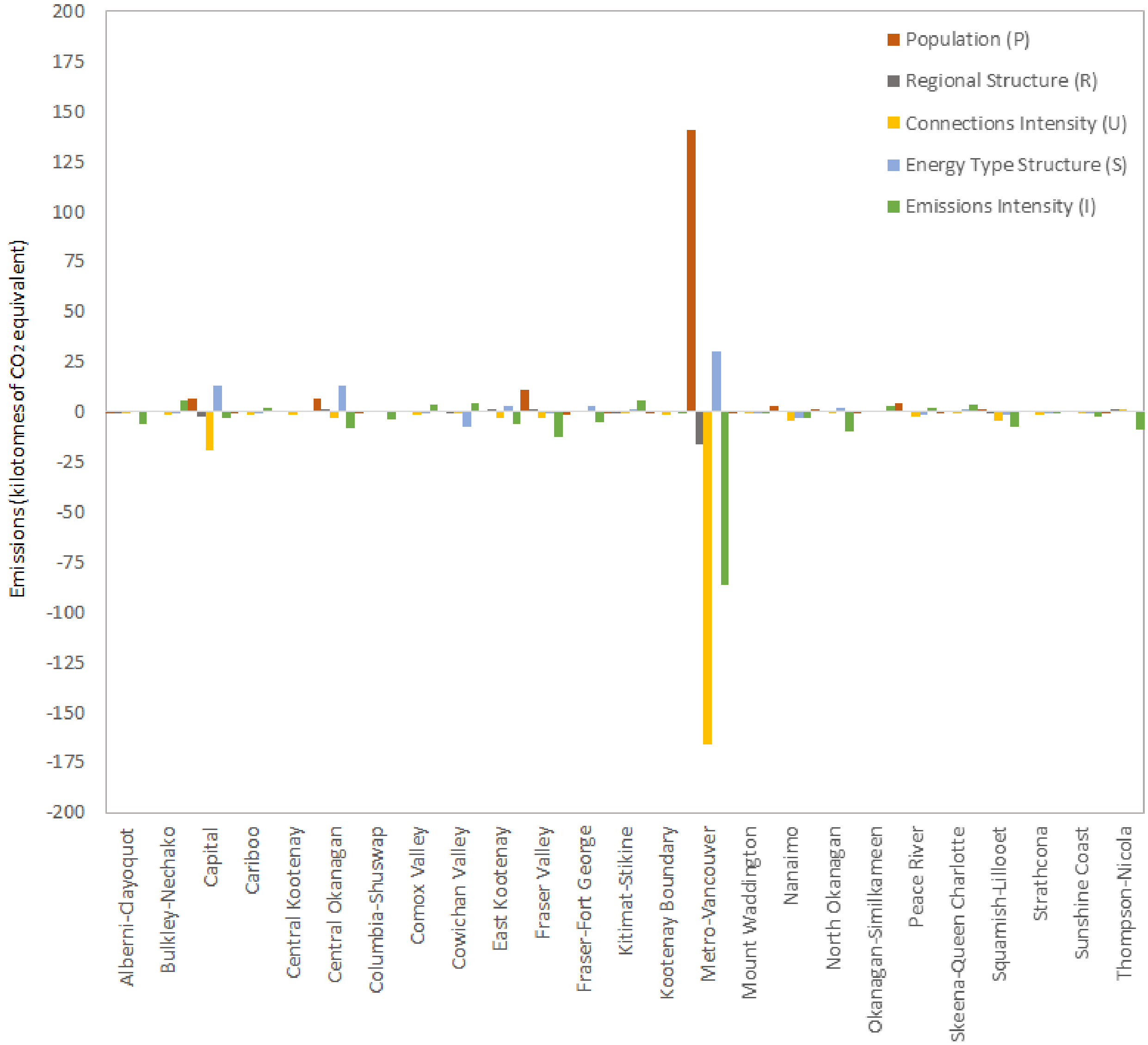

Figure 5. *Decomposition of commercial/industrial-related effects on GHG emissions for different BC regions*

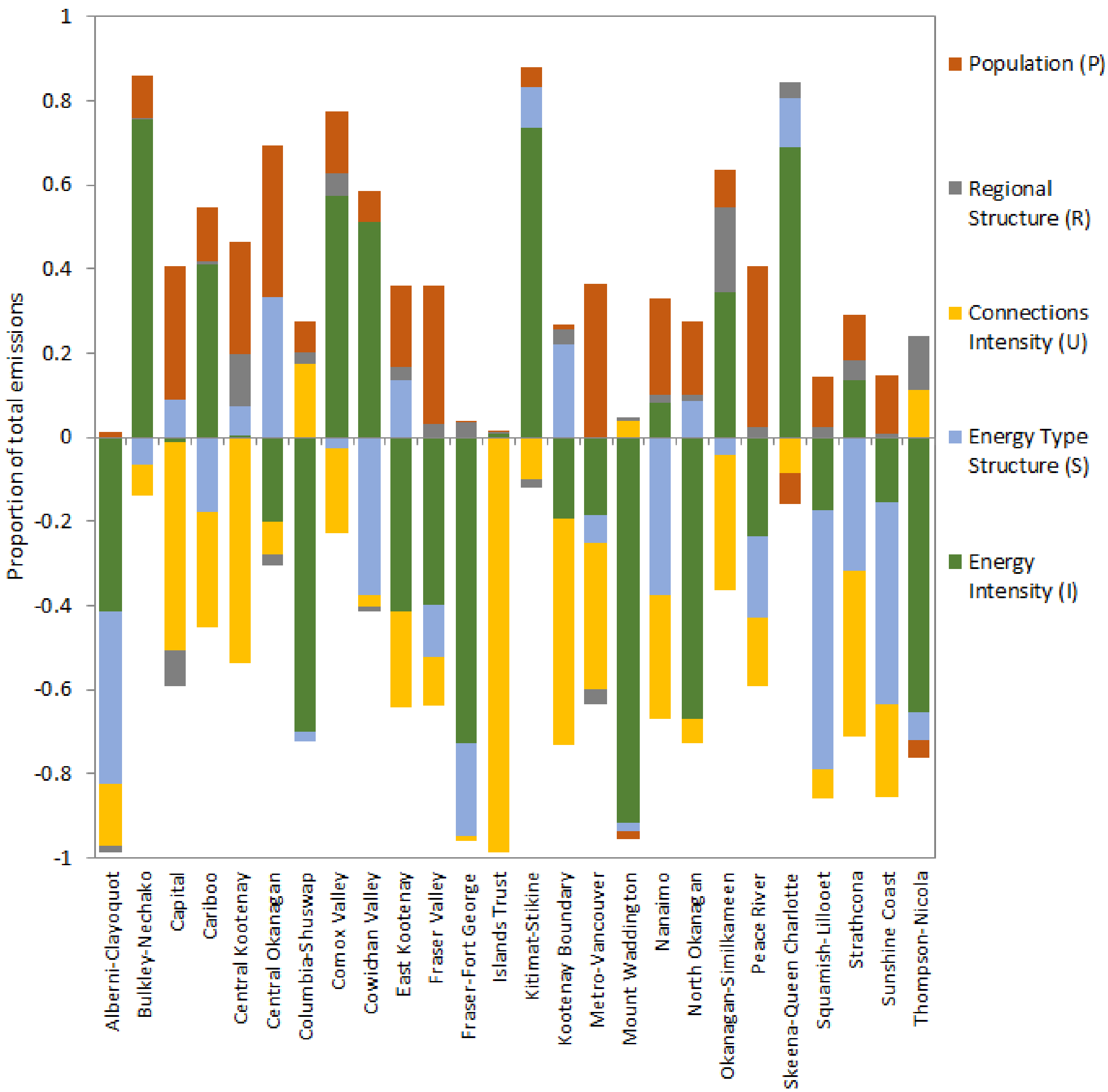

Figure 6. *Proportionate values of commercial/small-industrial-related effects on emissions for different BC regions*

4. COMPREHENSIVE ANALYSES AND PROVINCIAL OVERVIEW

4.1 Comparison of All Effects

An analysis was conducted that included all 18 effects (i.e., 6 from each of the three decompositions) in order to develop a comprehensive impression of which factors are significant in increasing and decreasing emissions. The analysis consisted of summing absolute values for all effects for each region, and then calculating and assigning (i.e., positive or negative) proportionate values for each effect. This allowed for comparisons of effect strengths among all factors and between different factor groups (i.e., vehicle, residence, commercial/small-industrial operations).

As noted above, vehicle emissions data is only available for certain regions (i.e., Metro-Vancouver and Fraser Valley) for 2012, and the transportation decomposition analysis only captures 2007 and 2010. Accordingly, the comparison of all factors below excludes 2012 data for all factors, and only presents changes in GHG emissions between 2007 and 2010.

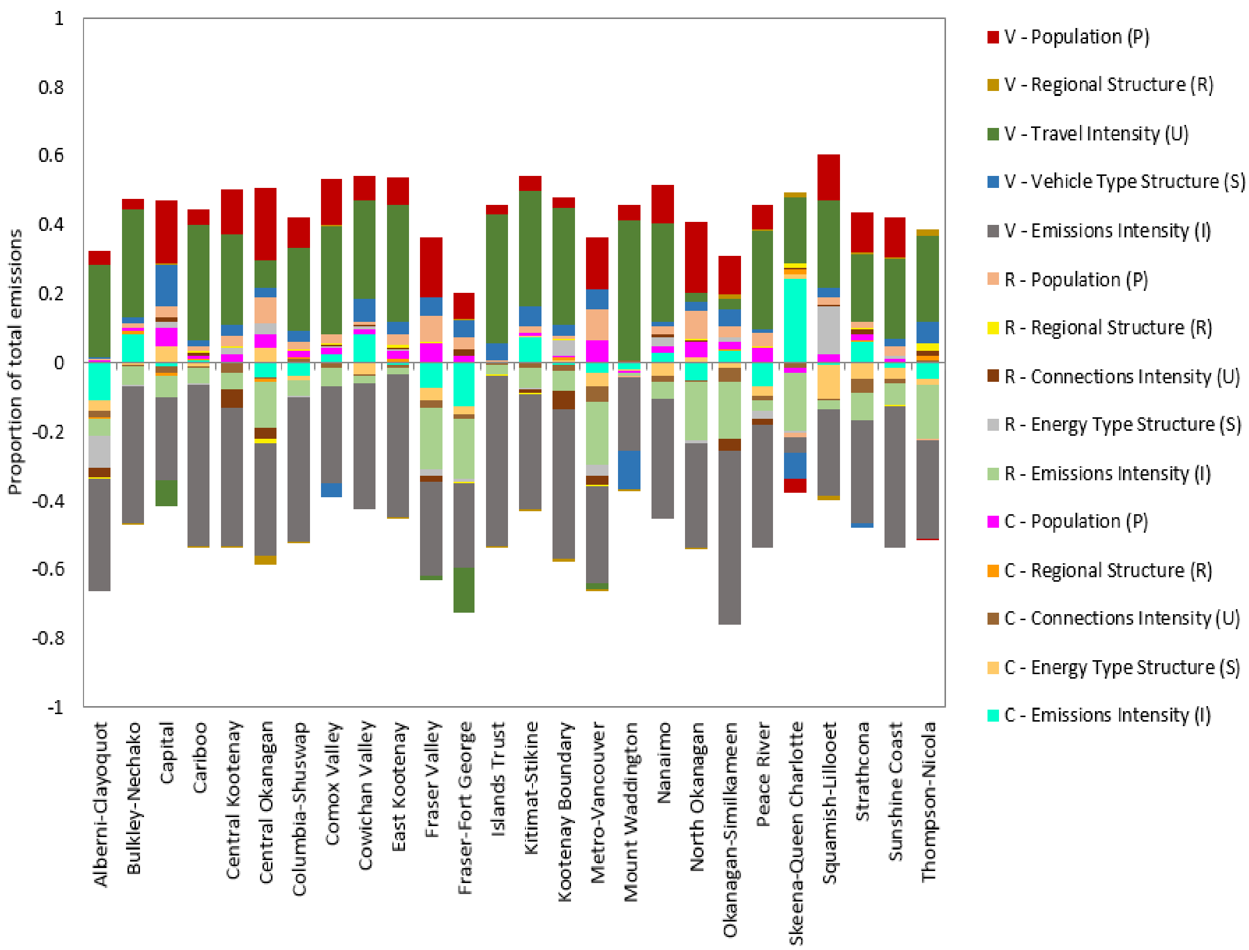

Figure 7. *Proportionate values of all effects on emissions for different BC regions (2007-2010)*

4.2 Provincial-level Analysis

Although an objective of this work is to design a procedure that analyzes emissions at the sub-provincial level, provincial analysis can also be conducted in order to gain an impression of the overall trends in effects on emissions. Such an analysis was done in this work using the same formulae as above, and the results are displayed on a single graph (Figure 8), ordered from strongest negative effect to strongest positive effect. As with the comparison of all effects (Figure 7), this analysis only uses 2007 and 2010 data.

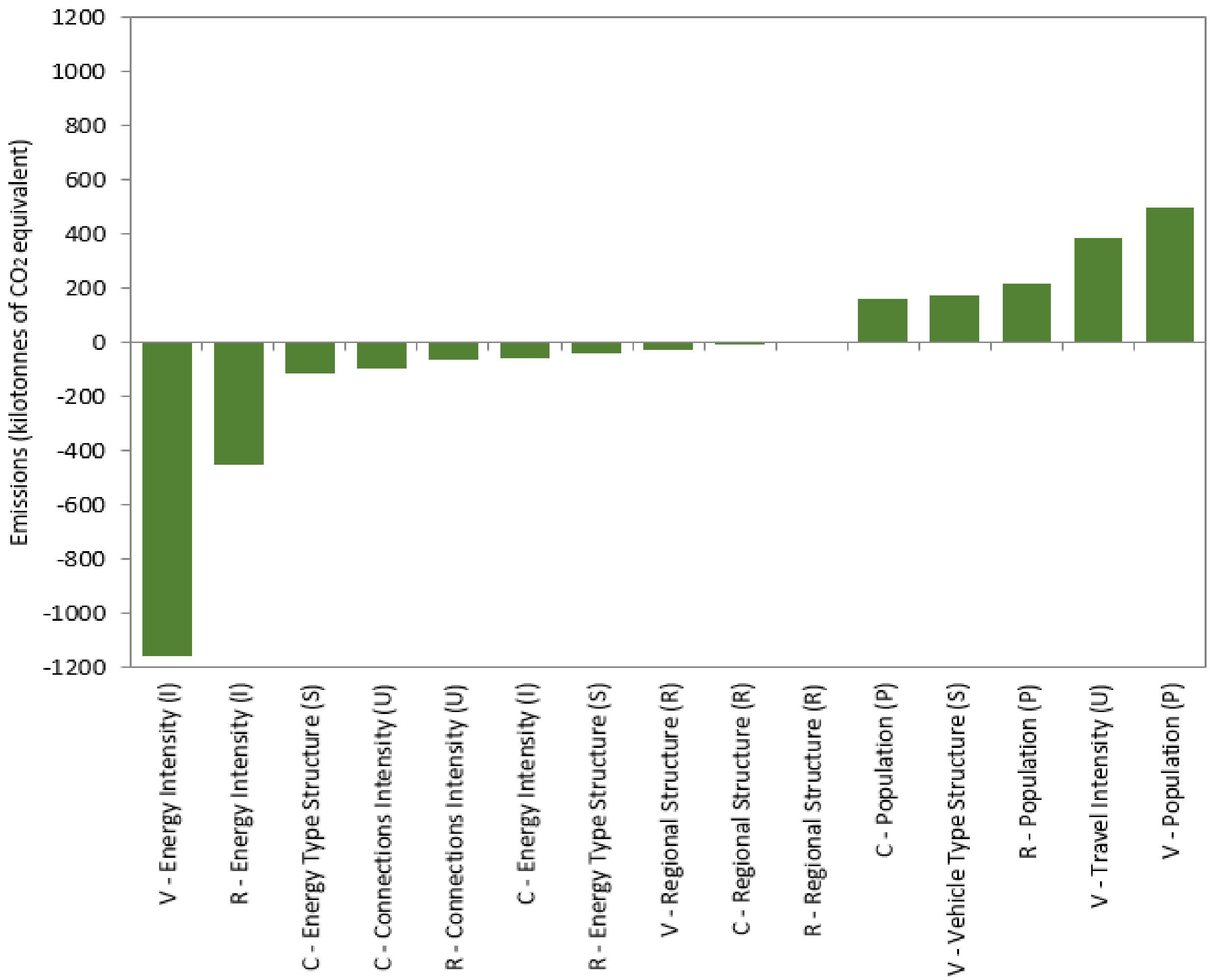

Figure 8. *Decomposition of effects on emissions for different regions in BC using provincial-level data*

Note: 'V' refers to vehicle-related (i.e., transportation) effects. 'R' refers to residence-related effects. 'C' refers to commercial/small-industry-related effects.

4.3 Results

As with the other sections, only brief descriptions of the findings are for the purposes of illustrating how decomposition output can be interpreted. Findings from the analyses show the following relationships.

- Vehicle-related population, vehicle travel intensity, and residential-related population effects have the strongest positive influence on emissions.

- Vehicle-related energy intensity, vehicle-related conversion factor, and residential-related energy intensity effects have the strongest negative influence on emissions.

- Of all three groups of effects, vehicle-related effects exert the strongest influences (positive/negative) on emissions.

5. VARIABLE OF INTEREST

Using a single figure to visually examining decomposition output for all BC regions can present certain challenges because variations in population magnitudes result in much larger effects in some regions than in others. When scaling the y-axis is to capture all output, this unevenness can 'dwarf' plotted values representing regions that have smaller populations. In the case of BC, Metro-Vancouver comprises over half the population of the province; thus, plotted values associated with this region are typically much larger than those of the other regions.

Changing the variable of interest can address the issue described above and allow for better display of decomposition output within a single figure. Decomposition analysis can involve examining either a variable that expresses total output (e.g., Heinen, 2013) or intensity of output (e.g., Torrie et al., n.d.), depending on whether an overall activity factor is (respectively) included or excluded. Therefore, instead of expressing the variable as total GHG emissions, the output variable could be expressed as emissions per capita by removing the population factor (i.e., overall activity) from the decomposition model. Because changing the variable of interest in this manner involves removing the population factor, it excludes the variable responsible for much the aforementioned unevenness.

An analysis was conducted that used residential factors and employed GHG emissions per capita as the variable of interest. The decomposition model is similar to the model described in *3.2 Residential Factors*; however, it differs in that the population (P) factor has been removed. The factors and formulae of the analysis were similar to those described in *3.2.1 Descriptions of Factors* and *3.2.2 Formulae for Factor Effects* with the only exception being that E refers to GHG emissions per capita in this analysis rather than total emissions.

Equation 33. $E = \sum R_i * U_i * S_{ij} * I_{ij}$

Equation 34. [Emissions per capita] = ∑ ([Population]$_i$ / [Population]) * ([Connections]$_i$ / [Population]$_i$) * ([Connections]$_{ij}$ / [Connections]$_i$) * ([Emissions]$_{ij}$ / [Connections]$_{ij}$)

Equation 35. [Regional Population Structure Effect] = $\sum L(E_i^T, E_i^0) * ln(R_i^T / R_i^0)$

Equation 36. [Connections Intensity Effect] = $\sum L(E_i^T, E_i^0) * ln(U_i^T / U_i^0)$

Equation 37. [Emissions Type Structure Effect] = $\sum L(E_i^T, E_i^0) * ln(S_i^T / S_i^0)$

Equation 38. [Emissions Intensity Effect] = $\sum L(E_i^T, E_i^0) * ln(I_i^T / I_i^0)$

* Where $L(a , b) = (a – b) / ln(a / b)$ for a≠b
When a=b, $L(a , b) = 0$ (Torrie et al., n.d.)
And, small value strategy ($\delta=10^{-100}$) for zero values (Ang and Liu, 2007)

Using GHG emissions per capita as the variable of interest holds the advantage of displaying of decomposition results for all regions in a clearer manner, as well as allowing for better comparisons of effects between regions. However, it is important to recognize that this approach to analysis does not capture total GHG emissions, and thus is not as useful for those wish to consider the output in terms of emissions targets. Therefore, the purpose and audience of a decomposition analysis should be considering prior to selecting the variable of interest to consider whether total output or intensity of output is more useful to those viewing and using the analysis.

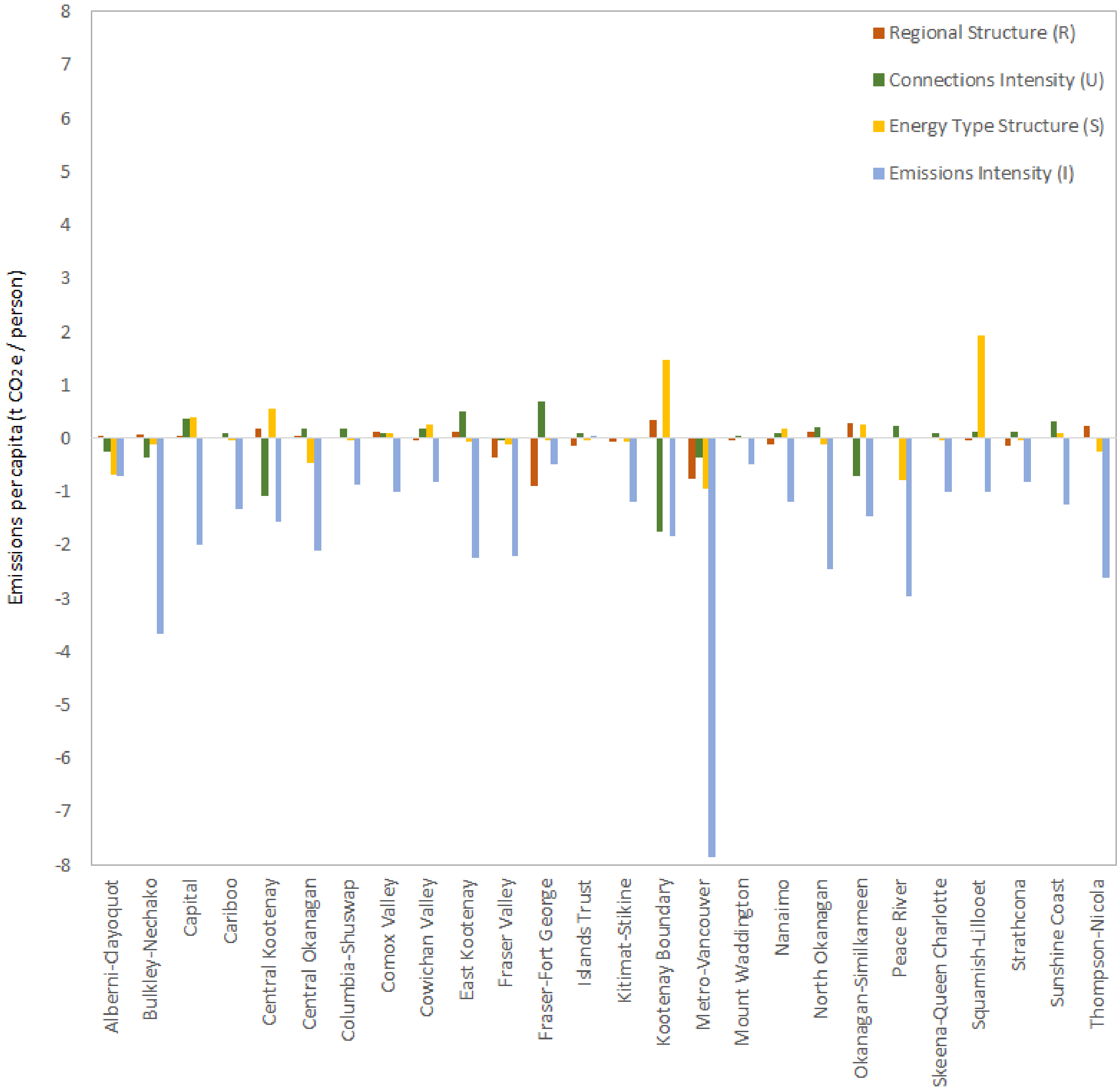

Figure 11. *Decomposition of residence-related effects on GHG emissions per capita for different BC regions*

6. COMMUNITY-SCALE DECOMPOSITION

In this analysis, decomposition was conducted at a regional level, and this was useful for considering vicinal municipalities as inter-linked communities. However, conducting the analysis at this scale also holds certain disadvantages, as it aggregates community data and (thus) can obscure emissions trends for individual municipalities. Therefore, some analysts might wish to conduct decomposition at the community-scale, and these analyses can serve as complements to regional-scale work. To provide an example, a community-scale decomposition analysis was conducted on residential energy use and emissions in Metro-Vancouver. The decomposition model is similar to the model described in *3.2 Residential Factors*; however, the regional population structure (R) has been removed.

Equation 12. $E = \sum P * U * S_i * I_i$

Equation 13. $[\text{Emissions}] = \sum [\text{Population}] * ([\text{Connections}] / [\text{Population}]) * ([\text{Connections}]_i / [\text{Connections}]) * ([\text{Emissions}]_i / [\text{Connections}]_i)$

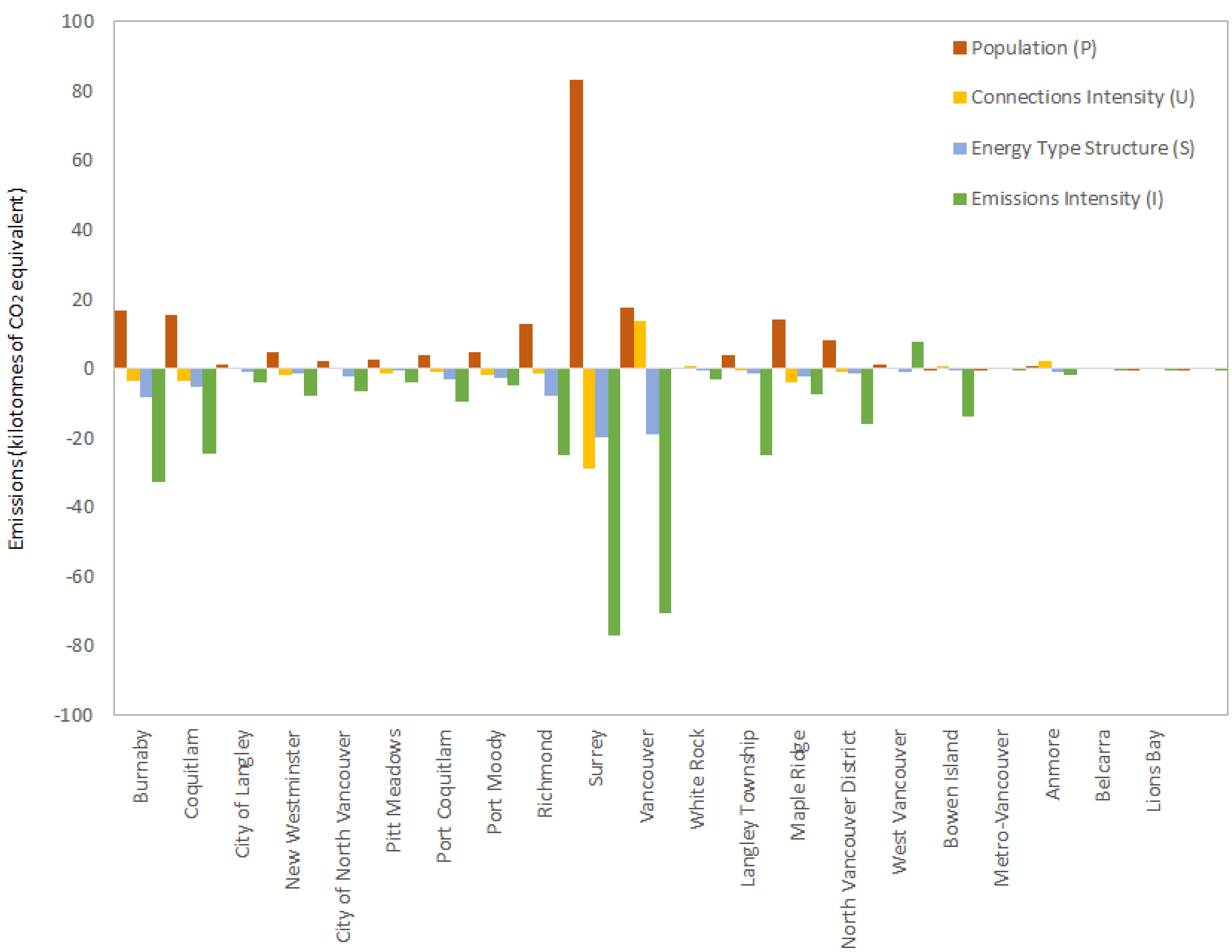

Figure 12. *Decomposition of residence-related effects on GHG emissions for different Metro-Vancouver communities*

7. INTEGRATING OTHER DATA

As aforementioned, the residence decomposition analysis is limited in the way that CEEI only contains residential connections data related to electricity and natural gas. Such limitations can be overcome by integrating other data into the analysis. For example, data on occupied dwellings can be used instead of connections data, and by doing this, CEEI estimates on other energy sources with no associated connections data, such as wood, heating oil and propane, can be included in the decomposition. Such a decomposition model would take the following form.

Equation 26. $E = \sum P * R_i * U_i * I_i * S_{ij}$

Equation 27. $[Emissions] = \sum [Population] * ([Population]_i / [Population]) * ([Dwellings]_i / [Population]_i) * ([Emissions]_i / [Dwellings]_i) * ([Emissions]_{ij} / [Emissions]_i)$

It is important to realize that although conceptually sound, integrating data from other data sources presents some practical challenges. In particular, data might not align properly in terms of year-of-collection. Referring to the example above, numbers of dwellings can be retrieved from census data; however, while census data is available for 2006 and 2011, it is not available for 2007, 2010 and 2012. This mismatch between data years creates difficulties for conducting a reliable analysis on integrated datasets, as it would involve using dwelling data for years nearest to 2007 (i.e., 2006), 2010 (i.e., 2011), and 2012 (i.e., 2011), rather than data collected for the same years. Such issues and challenges demonstrate the benefits of designing methodology and formulae that employ only the one data inventory and protocol (i.e., CEEI).

8. METHODOLOGICAL INSIGHTS AND CONCLUSIONS

Decomposition methodology consists of varied techniques and approaches and no 'standard' procedure exists (Ang, 2004). Accordingly, this work was designed to explore different methodological approaches and examine ways of employing decomposition analysis to interrogate community GHG emissions data. Although only 2007, 2010 and 2012 data were available for this analysis, the work has produced valuable insights on how to employ decomposition methodology for examining local-scale data and (subsequently) supporting local climate action. The following describes some of these insights.

1. **Defining the scale of analysis**. The purpose of this research was to determine how decomposition analysis can be employed to assist local policy and decision-making, and accordingly, the analysis was conducted at sub-provincial levels. However, it was determined that regional rather than local levels were more appropriate for the analysis, as emissions of nearby communities are linked

through activities that extend beyond municipal boundaries. For example, people living within Metro-Vancouver frequently travel from one city to another for work, recreation, and to access services and amenities. Analyzing data at the regional level allowed for decomposition models to be designed in such a way that inferences can be made around how population distribution through a metro area might affect emissions. More specifically speaking, a structural factor capturing the proportions of a region's total population located in different communities was included in the models, and such a factor can be examined for insights on how increases or decreases in urban density might influence emissions (e.g., more people living in suburban areas might lead to higher vehicle-related emissions).

2. **Balancing extensiveness and clarity**. The first attempt at developing decomposition models for CEEI data employed the basic formula comprised of activity, structural and intensity factors. In the transportation model, this consisted of total population change (i.e., activity), population distribution among different communities (i.e., structural), and vehicular emissions per person (i.e., intensity). It quickly became apparent that such simple models did not produce rich insights, and similar to that done in Ang (2012) and Jian (2015), the models were expanded. This allowed for more comprehensive examination and insight on other factors such as kilometers travelled per person and fuel efficiency of vehicles; however, expanding models also resulted in some difficult-to-interpret factors. Initially, the new model contained six factors and included a 'conversion factor' (Ang, 2012) that related to unit conversion from energy consumption to GHG emissions, but it was unclear as to what this factor meant in terms of behaviours and GHG production. Therefore, the model was once again refined, removing this factor. Such an iterative process demonstrates that designing decomposition model requires a balance between attempting to capture a wide breadth of factors and ensuring the factors are clear in how they can be interpreted.

3. **Selecting the terms and designing the model**. Decomposition formulae must be designed in such a manner that the units mathematically 'agree' with one another when disaggregating. For example, community population is a numerator in the population distribution factor of the transportation model; therefore, it also needed to be a denominator in another factor (i.e., kilometers travelled per person). This requires considerations around how to use available data to develop decomposition models that are mathematically sound, while also ensuring factors 'make sense' in the context of policymaking and interpreting them in meaningful ways (Jian, 2015). Addressing such a challenge is best addressed through collaboration with target users and stakeholders, in which decomposition models are presented to these groups in order to receive feedback on the usefulness and 'meaningfulness' of the factors (and then the models refined based on the feedback). In terms of MC^3's research, decomposition models have been presented to provincial government partners; however, more work is planned (and needed) around engaging different potential users, soliciting feedback, and refining models accordingly.

4. **Selecting the type of output variable**. Consideration needs to be given around the nature of the output variable. Decomposition analysis can involve examining either a variable that expresses a total (e.g., Heinen, 2013) or an intensity (e.g., Torrie et al., n.d.), depending on whether an overall activity factor is (respectively) included or excluded. In the context of MC^3's research, the output variable can be expressed as either total GHG emissions or emissions per capita. The former might more useful for municipal planners and decision-makers, as it could allow them to compare the output of the analysis to emissions targets. However, the latter could be of more interest to researchers because it could provide them with output that is not affected by population size, thus allowing for comparisons among a variety of different urban and rural regions.

5. **Using output to guide further investigation.** Some factors are relatively straightforward to interpret, whereas others might require some further probing to determine why a particular trend is occurring. An example of the latter includes the population structure factor included in the residence decomposition model. Similar to the transportation model, this factor captured proportions of population located in different communities, and it was included to make inferences around how urban density might influence residential energy use. However, in some case, making these inferences requires further investigation around whether the cities with increasing proportions of the population are indeed housing people in higher density dwellings, and such further inquiry could require examining data from other sources and in different ways. Ultimately, it is important to recognize that decomposition analysis can serve as a point of departure rather than a destination, and certain analytical outputs are best used for guiding further investigation.

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