



## Report

# Interactions of policies acting at the local, sub-national, and national scales for Canada's energy transition

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Energy Modelling Initiative

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## 1. Introduction

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Canada's energy transition is expected to involve policies that act at the local level, as well as at the sub-national and national levels. Until recently, energy and climate policy around the world was primarily the responsibility of sub-national and national governments, and there was a tendency to discount the potential of policies acting at the local scale. However, a growing number of cities have set ambitious mid-century targets for reduced greenhouse gas (GHG) emissions and/or increased reliance on renewable energy, bringing more attention to these policies. In Canada, major cities that have announced such targets include Toronto, Vancouver, Victoria, and Regina. More than 200 municipalities across the country have developed Community Energy Plans (Quest Canada, 2013).

There are a number of specific ways in which cities, alone or in partnership with other levels of government, can contribute to the electrification challenge. These fall into the two general categories of personal transportation and buildings. With respect to personal transportation, cities can get involved in the expansion of recharging infrastructure to facilitate the adoption of electric vehicles. Cities can also have a role in developing road pricing and/or parking charges that either favor electric vehicles or discourage personal vehicle use overall. It is certainly important that cities participate in the transition of municipally-owned bus fleets and commuter trains to zero-emissions energy sources. A switch from fossil fuel transportation to electric transportation can then be supported by expanding infrastructure for public transit, as well as for walking and cycling. Finally, cities are ideally positioned to influence urban form in ways that may reduce travel demand and increase the attractiveness of mode shifting away from the personal vehicle. Through their jurisdictional powers in the areas of zoning, development permitting, and property taxation, cities can seek to increase population density and encourage mixed-use development, possibly in coordination with mobility infrastructure. When it comes to buildings, cities may have a role in revising building codes in order to improve the energy efficiency of the building stock and promote a switch from fossil fuels to electricity for space and water heating.

Because of the emerging importance of policies acting at the local scale, planning for Canada's transition to a Clean Electric Future requires enhanced modelling capabilities. Sophisticated energy-economy models are available for analysing the impacts on energy use and GHG emissions from one or a portfolio of policies. However, as these models were designed mainly to account for policies with impact at the global, national, or sub-national levels, they are not always capable of integrating policies at the local level. In particular, existing energy-economy models tend to lack a spatial dimension, making it difficult to address many of the actions targeted by such policies. For example, a policy



that seeks to increase the convenience of public transportation by building a dedicated rail line or providing a frequent rapid bus service will not do so uniformly across the city, but will instead cause a greater increase in convenience for those living and/or working near the new route. Models at the city scale do exist; however, these policy assessment tools are not as advanced in some ways as their counterparts at the sub-national and national levels (Keirstead et al., 2012).

In particular, models used to simulate decisions around energy use by households and firms must take into account factors in addition to the observed costs of the different options (see Allcott and Greenstone, 2012; Jaffe and Stavins, 1994; Sutherland, 1991). An electric vehicle has an up-front cost, on-going electricity and maintenance costs, and (eventually) a cost associated with battery replacement. However, in deciding between a conventional vehicle and an electric one, consumers attach value to other attributes, such as range, availability of charging stations, perceptions of others, and how established the technology is. Likewise, public transit users must pay a fare but are also influenced by considerations of trip time, convenience, status, and comfort.

Analytical tools are needed that can not only address local scale policies to advance electrification but also take into account the interactions of related policies acting at the sub-national and national scales. When policy interactions exist, it is not as simple as adding the impacts from separate modelling efforts. Policies can overlap in terms of the actions they cause, leading to a less than additive effect. It is also possible for one action to reduce the potential for another action. For example, a shift to clean electricity for heating our homes and buildings would reduce the GHG impact of building shell energy efficiency improvements. On the other hand, policies can complement each other by causing different actions. It is even possible for policies implemented together to result in a more than additive effect. Investment in electric rapid transit infrastructure could interact in this way with policies that encourage compact development around the rapid transit stations.

We have developed an urban spatial model of energy use and GHG emissions that: 1) captures unobserved values that have an influence on the energy decisions of households and firms, and 2) is capable of simulating the interactive effects of policies at different scales. We achieved these two objectives by integrating our longstanding energy-economy model, called CIMS, with an urban land use and infrastructure model to create the CIMS-Urban model. We are aware of no other urban spatial model operating in Canada that has these capabilities. In the following sections, we describe our Energy Modelling Initiative project, in which we apply CIMS-Urban to test how policies acting at different levels of government can interact to affect urban energy use and GHG emissions in the City of Vancouver.



## 2. The model: CIMS-Urban

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We have developed a spatially explicit version of the CIMS energy-economy model, called CIMS-Urban, by integrating an urban-scale CIMS model with a GIS model. CIMS-Urban can simulate the interaction of policies acting at the local scale with policies acting at the sub-national and national scales, and it can do so in a way that realistically represents human behavior. Here, we describe the original CIMS energy-economy model and the urban land use/infrastructure GIS model that together form CIMS-Urban.

A Vancouver version of CIMS-Urban is well developed and has been used to test the potential for the city to achieve ambitious renewable energy and GHG emissions reduction targets (Jaccard et al., 2019). We are currently extending this model to all of Metro Vancouver, so as to be able to simulate multi-city commuting behavior. The next applications to major metropolitan areas will be for Toronto and Montreal. CIMS has recently been used to model energy and emissions in Victoria and Nanaimo (BC). We are investigating ways to apply our urban modelling tools across cities of different sizes.

### 2.1. The CIMS energy-economy model

CIMS was developed in the context of sub-national and national energy and climate policy simulation. The model has been used extensively to assess the effectiveness and costs of such policies, both in an academic context, and for clients including governments, industry associations, and non-governmental organizations. It is the subject of numerous academic articles, including those by Jaccard (2009) and by Murphy and Jaccard (2011), which describe the model in detail.

CIMS is unique in that it represents the acquisition, use, and retirement of energy-related technologies in a way that takes into account values that, while not directly observed, have a significant influence on human decisions. CIMS is technologically explicit, tracking the turnover of the capital stock, namely infrastructure, buildings, industrial plants and equipment, electricity generation and other energy supply equipment, vehicles and other transport equipment, and appliances and other household durable goods. In simulating the decisions of households and firms, the model considers not only the market costs of the different options but also their unobserved costs and benefits. This allows for a more realistic simulation of human behavior. The behavioral parameters within the CIMS are empirically estimated from a combination of market research into past technology choices (revealed preferences) and discrete choice surveys of possible future technology choices (stated preferences) (Rivers and Jaccard, 2006).

CIMS simulates the turnover of infrastructure, buildings, factories, and equipment over time through retirements, retrofits, and new acquisitions. In each 5-year period, a portion of the existing capital stocks are retired according to an age-dependent function, although accelerated retirement and retrofit are possible if warranted by



economic conditions. As new capital stocks are required, technologies compete for market share based on an algorithm that is applied at several levels of decision-making. For example, at one level there is competition among different private vehicle technologies, which is nested inside a higher-level competition between modes of transport, the mode options being private vehicles, public transit, cycling, and walking.

The CIMS technology competition algorithm is given in Equation 1.  $MS_j$  is the market share of the new capital stock captured by technology  $j$ ,  $CC_j$  is its capital cost,  $n_j$  is its average lifespan,  $MC_j$  is its annual maintenance and operation cost, and  $EC_j$  is its annual energy cost, which depends on energy prices and energy consumption. The costs of technology  $j$  are compared to those of all other technologies ( $K$ ) available to provide the energy service in question (e.g. heated indoor floor space, person-kilometers travelled).

$$MS_j = \frac{[CC_j * \frac{r}{1-(1+r)^{-n_j}} + MC_j + EC_j + i_j]^{-v}}{\sum_{k=1}^K \{ [CC_k * \frac{r}{1-(1+r)^{-n_k}} + MC_k + EC_k + i_k]^{-v} \}} \quad (1)$$

In addition to these standard financial costs, the market share algorithm includes three behavioral parameters, each of which characterizes a different aspect of firm and household decision-making. Thus, there is a time preference parameter ( $r$ ) representing the trade-off between present and future costs for the technologies in the competition (e.g., higher upfront cost versus lower operating cost), a parameter ( $v$ ) that denotes the heterogeneity of decision-makers, and an (annual) intangible cost parameter ( $i$ ) that can vary by technology. An example of this last parameter is the intangible cost value for public transit in the personal mobility mode share competition, which is based on revealed and stated preference research showing that a significant share of consumers attach an intangible, non-financial cost to public transportation that reflects their perceptions of its lower convenience, status, and comfort relative to the private vehicle.

The original source for data on industrial technologies in CIMS was the Industrial Sector Technology Use Model (ISTUM) developed by the U.S. Department of Energy (1983). These data were significantly updated at Simon Fraser University in the mid to late 1990s to create the Intra-Sectoral Technology Use Model (also called ISTUM) (Nyboer, 1997). There are various additional sources for the current CIMS technology database, including public statistical agencies, energy utilities, literature reviews, industry associations, equipment manufacturers, and surveys of sector experts. Because there is a lack of detailed information on annual energy consumption of the individual capital stocks tracked by the model (especially smaller units), these must be estimated from surveys at different levels of technological detail and by calibrating the model's simulated energy consumption to real-world aggregate data. The behavioural parameters in CIMS ( $v$ ,  $i$ , and  $r$ ) are estimated from stated and revealed preference data (Axsen et al., 2009; Horne et al., 2005; Jaccard and Dennis, 2006; Rivers and Jaccard, 2005; Washbrook et al., 2006).



CIMS also includes two functions for simulating endogenous change in the real and perceived characteristics of technologies that are new to the market: a declining capital cost function and a declining intangible cost function. These functions are especially important for modelling policies that pursue technological transformation of the energy system over the next few decades. The declining capital cost function (Equation 2) links a technology's capital cost in future periods to cumulative production, reflecting economies-of-scale and economies-of-learning that lower capital costs. In the equation,  $CC(t)$  is the capital cost of a technology at time  $t$ ,  $N(t)$  is the cumulative production of that technology at time  $t$ , and  $PR$  is the progress ratio, defined as the percentage reduction in cost associated with a doubling of cumulative production.

$$CC(t) = CC(0) \left[ \frac{N(t)}{N(0)} \right]^{\log_2(PR)} \quad (2)$$

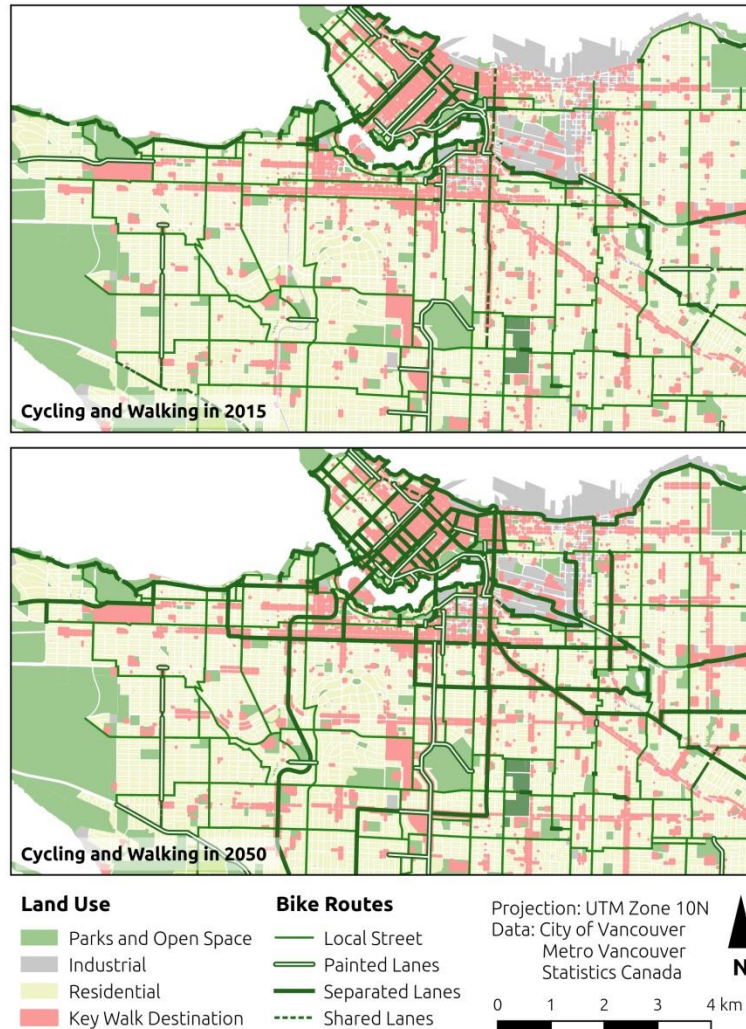
The declining intangible cost function links a technology's intangible cost in a given period with its market share in the previous period. This 'neighbor effect' reflects how consumer perceptions of risk decline as a new technology gains market share (Mau et al., 2008). Intangible costs for technologies decline according to Equation 3, where  $i(t)$  is the intangible cost of a technology at time  $t$ ,  $MS_{t-1}$  is the market share of that technology at time  $t - 1$ , and  $A$  and  $k$  are estimated parameters reflecting the rate of decline of the intangible cost in response to increases in the market share of the technology.

$$i(t) = \frac{i(0)}{1 + Ae^{k * MS_{t-1}}} \quad (3)$$

## 2.2. Urban land-use and infrastructure model

The GIS component of CIMS-Urban tracks changes in land use (increased density, mixed-use development) and the development of energy distribution and mobility infrastructure. An example of such evolution of urban form within the model is provided in Figure 1, which compares the land use pattern and cycling network in Vancouver in 2015 with a projection for 2050 under its Renewable City Strategy. As one can see, in 2050 there are more thick lines indicating high-quality cycling routes and more of the pink urban areas indicating high walkability. These changes, in turn, affect the intangible cost values in the CIMS personal mobility mode share competition and total travel demand in the form of person-kilometers travelled. Thus, a mixed-use, higher density development can decrease the distance of many residents to a commercial area, thereby reducing overall travel demand and lowering the intangible cost in CIMS of the personal mobility choice of walking for some types of mobility needs.





**Figure 1: Vancouver’s land use pattern and cycling network in 2015 and in 2050 under its Renewable City Strategy**

Travel demand in CIMS-Urban is determined by a person-kilometers travelled (pkt) algorithm (Equation 4), which measures future changes in population and land-use. Baseline year per-person pkt values are exogenously sourced from data and transformed into estimated future pkts by way of calculated index values that replicate percent changes in travel demand over time. Travel demand is calculated on small locational scale, specifically the 992 Dissemination Areas (DA) for Vancouver according to Statistics Canada (2011a). The algorithm calculates a pkt index value for a specific DA and time period ( $PKT Index_{t,DA}$ ) by summing the distances ( $d_{DA,k}$ ) between the DA and



closest commercial and institutional districts ( $k$ ). The calculated index values are then multiplied by the DA's local population ( $p$ ) to account for the impacts of population density and growth. City-wide per capita index values representing change in travel demand are extrapolated by averaging all DA-specific indexes in Vancouver and dividing by total population at every simulation year. The per-person pkt index values for each simulation year are normalized relative to the baseline year, thereby permitting all changes in mobility to be reported as a city-wide percent change in per capita travel demand. The normalized per-person pkt index values are multiplied by the exogenously derived baseline year per-person pkt estimate to produce aggregated per capita travel demand values for Vancouver. The aggregated per capita pkts are multiplied by the corresponding total population in Vancouver for every simulation year to produce travel demand values that are entered into the CIMS personal transportation sector market share algorithms to allocate specific mode shares.

$$PKT Index_{t,DA} = \sum_{k=1}^n (d_{DA,k})^W \times p_{DA} \quad (4)$$

We assume that the intangible cost of a given personal mobility mode at a particular location is a function of that mode's network quality at the location and a constant value for each mode, which we refer to as its 'network quality coefficient.' A relatively high network quality value decreases the intangible cost, whereas a relatively low network quality value increases it. To estimate the intangible cost under policy conditions, we must first solve for the network quality coefficient under baseline conditions by estimating the baseline intangible cost and the baseline network quality. Then, we can calculate the network quality under policy conditions and apply the network quality coefficient to solve for the policy intangible cost. Estimates of network quality are generated by mode for neighborhoods across the city, based on 'network quality equations' within the GIS model. These network quality values change over time depending on policies that affect land use and transportation infrastructure in different areas.

From the CIMS market share algorithm, it is possible to estimate the intangible cost associated with a mode of transportation, given assumed values for the other behavioral parameters and known mode shares and financial costs. However, it is not possible to solve the algorithm algebraically for the intangible cost of a single technology or mode, which therefore must be solved analytically. We used the Nelder and Mead optimization technique (Nelder and Mead, 1965) in R (R Core Team, 2016) to solve for a baseline intangible cost value for each personal mobility mode in each of Vancouver's 22 planning neighborhoods. The intangible cost of driving a private vehicle was assumed to be zero under baseline conditions.

CIMS-Urban evaluates transportation network quality separately in four categories: road network quality (for private vehicle users), walking network quality, cycling network quality, and public transit network quality. Road network quality ( $Q_r$ ) is calculated on the



neighborhood scale according to Vancouver’s 22 neighborhoods, as in Equation 5. Each road segment (*RS*) in a given neighborhood is assessed in terms of its length (*l*) and assigned a quality value (*q*) based on the road type. From highest to lowest value, road types are: freeway, arterial, collector, local, lane/strata, and trail/restricted/other. The product of *q* and *l* is taken, and the result averaged across all the road segments. This average is then divided by the product of the neighborhood’s population density (*pd*) and its estimated pkt index value (*pkt*), as a proxy for how changes in local population and travel demand may affect road congestion.

$$Q_r = \frac{\sum_1^{nRS} q \times l}{n} / (pd \times pkt) \quad (5)$$

Walking, cycling, and public transit quality are calculated on a finer locational scale – the 992 DAs in Vancouver – because individuals who walk or cycle are somewhat more sensitive to distance than those who drive. We excluded DAs located within the downtown Vancouver central business district as the small number of residents in this high traffic area could bias results.

Almost all roads in Vancouver have safe sidewalks to accommodate pedestrians; therefore, we assumed that walking path quality is the same everywhere and that the distance to commercial and employment areas from a DA is the key factor in determining walk network quality. We used a logistic decay function to describe how distance initially would have a relatively small impact on walk quality, but would grow in importance once individuals had to walk more than just a few minutes. Walking network quality (*Q<sub>w</sub>*) is estimated at the DA level using Equation 6, in which a calculation is carried out for each walk destination (*WD*) in the city, and the results are then summed across all of the destinations. Here, *d<sub>min</sub>* describes the shortest possible distance between any point on the DA boundary and the walk destination. The parameters for the walk quality and public transit quality equations (see Equation 8 below for transit quality) were developed empirically to produce results reflective of how far the average person will generally walk to a destination. For example, most people are likely willing to walk about 5 minutes to a bus and 10 minutes to a store, other business, or rapid transit.

$$Q_w = \sum_1^{nWD} \frac{1}{1 + e^{\frac{\ln(19)}{200} \times d_{min} - 200}} \quad (6)$$

Cycling network quality for a given DA (*Q<sub>c</sub>*) is derived according to Equation 7. The calculation is done for each cycling route (*CR*) in the city, and the results are summed across all of the routes. Here, *d<sub>min</sub>* is the shortest possible distance between any point on the DA boundary and any point on the cycling route, *d<sub>max</sub>* is the furthest possible distance (straight-line) from the *d<sub>min</sub>* point on the route to any point on the DA, *l* is the length of the route, and *q* is a quality value based on the route type (highest for separated lanes or paved paths, lowest for shared lanes). Because distances for the cycling calculation are to linear features, we used a simple inverse distance relationship



instead of logistic decay, as this method resulted in less abrupt changes in cycling quality among adjacent DAs.

$$Q_c = \sum_1^{nCR} \frac{1}{0.5 \times (d_{min} + d_{max})} \times l \times q^2 \quad (7)$$

Public transit network quality ( $Q_t$ ) is estimated at the DA level as the sum of two components (Equation 8), each of which resembles the walk quality equation. The first component represents 'regular' transit stops (*RegTS*) and the second represents 'rapid' transit stations (*RapidTS*). Rapid routes are defined as not only fast and high frequency, but also on a dedicated right-of-way, meaning they are not subject to traffic delays. In the equation,  $d_{min}$  is the shortest possible distance between any point on the DA boundary and the stop or station,  $d_{max}$  is the furthest possible distance, and  $f$  refers to the frequency of service at the stop or station. Frequency is weighted highly in the calculations to reflect the importance of high frequency public transit service to customers' feelings of autonomy and satisfaction. People are generally willing to walk further to rapid transit than to a regular bus line; therefore, the contribution a bus stop makes to service quality declines more quickly with distance than the contribution from a rapid transit station.

$$Q_t = \sum_1^{nRegTS} \frac{1}{1 + e^{\frac{\ln(19)}{200} \times 0.5 \times (d_{min} + d_{max})}} \times f + \sum_1^{nRapidTS} \frac{1}{1 + e^{\frac{\ln(19)}{400} \times 0.5 \times (d_{min} + d_{max})}} \times f \quad (8)$$

Baseline transportation quality calculations were conducted within the GIS model using current road network, land-use, cycling route, and public transit network data for Vancouver. For the GIS calculations, we used PostGIS 2.1 in a PostgreSQL 9.4 database (The PostGIS Development Group, 2015). The GIS database software configuration is similar to what has been used in previous research mapping and modelling urban GHG emissions and it is flexible enough to be expanded to larger applications (Gkatzoflias et al., 2013).

The first step in calculating a distinct network quality coefficient for each personal mobility mode was to take the average of the baseline network quality estimates across all of the DAs within each of the 22 neighborhood zones. We then used the least-squares method to fit a trend-line to the baseline network quality and intangible cost data for each mode. In the case of the public transit mode, we 'log transformed' quality data to improve fit. Log transforming helped normalize the data that was otherwise dominated by a few areas of very high transit service quality, such as around transit hubs. Because there is substantial uncertainty around the relationship between network quality and intangible cost, we ran some sensitivity tests using different values for the network quality coefficients and found that, while extreme differences in the coefficients could lead to detectable differences in mode share, the likely differences in energy use and emissions for Vancouver overall were negligible.



The network quality algorithms and their coefficients allowed us to estimate new intangible costs based on policies that modify Vancouver’s transportation network, land use, and built environment. First, we calculated policy network quality estimates for the duration of our simulation period, which extends from 2015 to 2050, by representing transportation and zoning changes within the GIS. Then, as in deriving the network quality coefficients, we averaged these network quality estimates at the neighborhood zone level. Next, we applied the mode-specific network quality coefficients to obtain a per-person intangible cost for each travel mode/neighborhood zone combination, over the simulation period. Finally, we multiplied each calculated intangible cost by its corresponding neighborhood population before summing the resulting value across all neighborhoods and dividing by Vancouver’s total estimated population to produce a city-wide per-person intangible cost estimate for each mode choice. The mode-specific intangible costs, weighted by population, were incorporated into the CIMS technology competition algorithm to help determine changes to transportation mode share over the simulation period.

There were significant input data requirements associated with building the version of CIMS-Urban used in this study, both to update key CIMS parameters from model defaults (averages for the province of British Columbia) and to populate the spatial component. The data sources we used are given in Jaccard et al., 2019.



### 3. Policy scenarios tested

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We tested a series of policy scenarios in CIMS-Urban. These scenarios were designed to assess the extent to which policies operating at the urban scale in Vancouver, such as investments in public transit infrastructure and changes in land use, can be used to supplement carbon pricing and the other complementary policies in order to achieve GHG emissions reduction. In designing the policy scenarios, we took into account the existing Pan-Canadian Framework and other federal and provincial initiatives, as well as possible new policies. We considered a range of senior government policies that are expected to vary in terms of their interactions with municipal policies and constructed scenarios that probe these interactions.

In order to describe the policy scenarios tested and interpret the modelling results that follow, it is important to distinguish between actions and policies. Actions are changes that cause GHG emissions reductions. Two key actions are improving the efficiency with which we use energy and switching to low- or zero-emissions energy forms. Policies are efforts by public authorities to cause actions. A wide range of policy options are available, including carbon pricing, regulatory instruments, subsidies to individuals or to firms, information programs, and government procurement programs. Local, sub-national, and national governments vary in terms of their jurisdictional authority to implement policy. Municipal governments tend to control land use through zoning, some aspects of the built environment through codes, and some aspects of urban mobility. Senior levels of government, on the other hand, tend to have greater taxation and regulatory authority over technologies and fuels.

The scenarios we tested include two categories of government policies: 1) policies whose main impacts on energy and GHG emissions are due to changes in urban-scale spatial relationships and 2) other policies. The spatial policies tend to fall within the jurisdiction of municipal governments. Therefore, we refer to these policies as “municipal policies” in the headings below. The non-spatial policies tend to fall within the jurisdiction of sub-national or national governments. Therefore, we refer to these policies as “senior government policies” below.

For the most part, building codes do not influence energy and GHG emissions through changes in spatial relationships. Therefore, we categorize building codes as senior government policies. Within Canada, jurisdiction over building codes actually varies by province. In BC and Quebec, for example, municipalities hold considerable control over the building code regulations they follow, whereas in other jurisdictions, such as Ontario, local governments do not have such powers. The zero-emissions building policy we simulate is, in fact, based on the Zero Emissions Building Plan of the City of Vancouver; however, we include it in a senior government policy portfolio because it is a



non-spatial policy that could require senior government support in a number of jurisdictions.

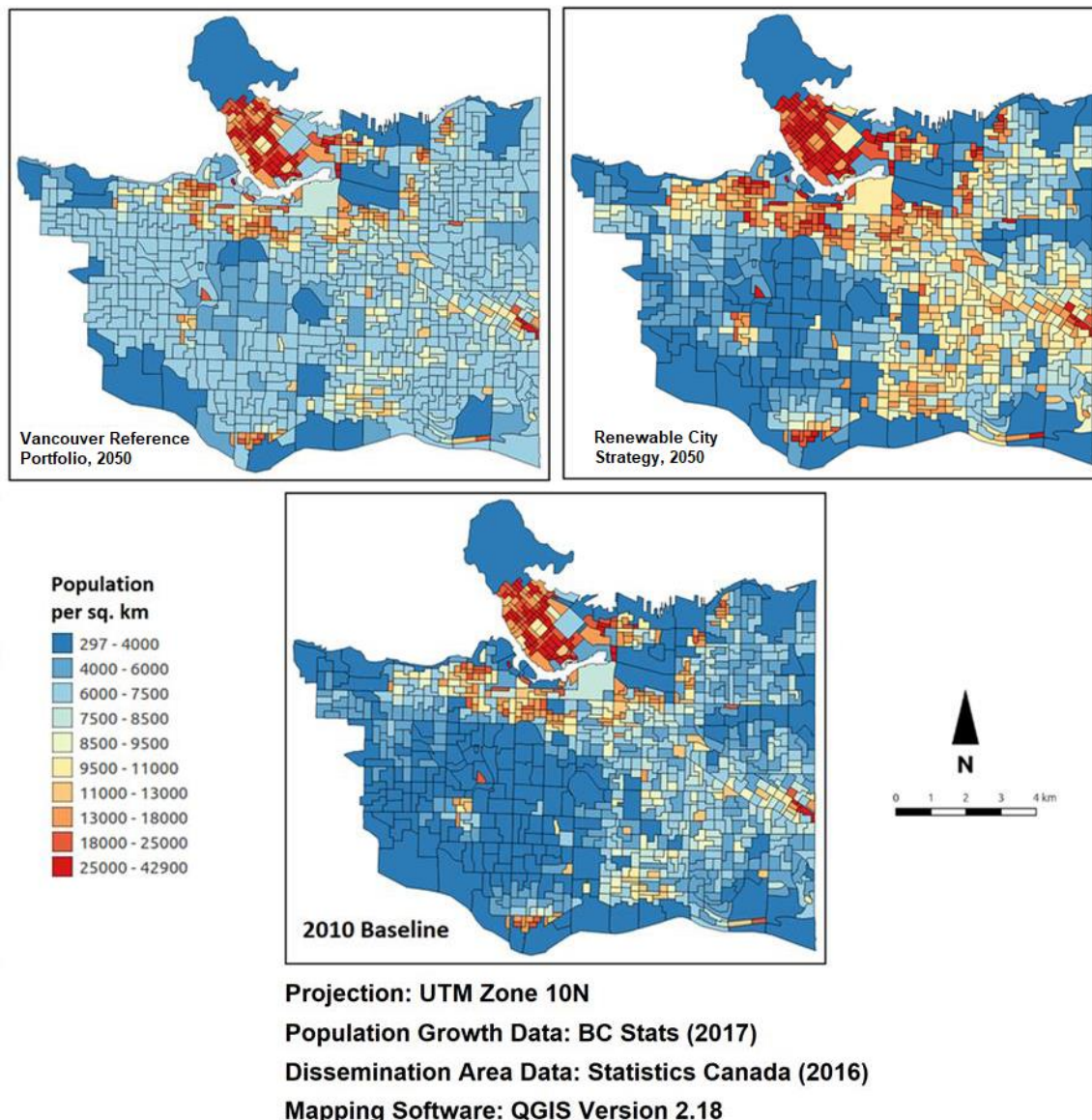
### 3.1. Municipal policy portfolios

Due to geographic constraints, Vancouver cannot expand in physical size and therefore we assumed that growth in all scenarios would be through increasing density.

Population growth in CIMS-Urban was based on forecast data for Vancouver provided by BC Stats Sub-Provincial Population Projections (BC Stats, 2017).

**Vancouver reference portfolio:** This portfolio includes a number of policies of the City of Vancouver’s municipal government, at their announced design and stringency levels as of 2016. Among these are the policies that were in place at that time to promote electric and zero-emissions vehicles. In our simulation of this portfolio, public transit service levels and cycling routes are maintained with population growth, but not substantially improved. Land-use policy dictating the location of commercial, institutional, and mixed-use districts remains unchanged. Population growth in the reference portfolio is simulated to take place in the lowest density areas in the city mostly representing conversions of single detached housing neighborhoods to contain more duplexes and triplexes. The map at the top left of Figure 2 illustrates resulting population densities in 2050, with the lower map providing baseline population densities in 2010 for comparison.

**Renewable City Strategy portfolio:** In 2015, Vancouver launched its Renewable City Strategy (City of Vancouver, 2015b). Our simulation of this policy portfolio includes transportation network improvements, mixed-use pedestrian-oriented developments along major public transit routes, and more high-density development nodes centered on rapid transit stations. Road network changes, cycling improvements, and new public transit infrastructure investments to 2050 are hypothetical, but those simulated are consistent with the Renewable City Strategy, Vancouver’s Transportation 2040 Plan (City of Vancouver, 2012), and the regional transit authority’s 10-year plan (Mayors’ Council on Regional Transportation, 2014). Population growth to 2050 in the *Renewable City Strategy portfolio* is simulated to proportionately increase across Vancouver to reflect a balanced density policy. Population increases concentrate along major transit corridors and hubs as transportation infrastructure is improved and some modest growth occurs in single detached housing neighborhoods, as illustrated by the map at the top right of Figure 2.



**Figure 2: Population density scenarios used for the *Vancouver reference* and *Renewable City Strategy* portfolios**

### 3.2. Senior government policy portfolios

The policies included in the *senior government reference* portfolio, as described below, are maintained for all of the other senior government portfolios that follow, except in the case of the building code. The reference case version of the building code is altered in the *zero-emissions building portfolio*. The carbon price portfolios and the *zero-emissions vehicle* portfolio add the named policies to the reference portfolio.





**Senior government reference portfolio:** This portfolio includes the following policies: the BC Low Carbon Fuel Standard, announced federal and provincial zero-emissions vehicle subsidies, current federal vehicle emissions standards on light-, medium-, and heavy-duty vehicles, and current federal minimum energy performance standards for appliances. We modelled the BC Low Carbon Fuel Standard as a biofuel blending requirement of 10% ethanol in gasoline and 10% biodiesel in diesel fuel by 2020. The building code in this scenario is that which existed in 2016 for commercial and residential buildings.

**Current carbon price portfolio:** Here, we add the British Columbia carbon tax to the *senior government reference* portfolio. The carbon price increases in line with the federal government carbon price backstop to \$50/tonne CO<sub>2</sub> by 2022, where it remains in real terms until 2050. Funds collected through carbon pricing are assumed to go into senior government general revenues.

**Paris carbon price portfolio:** The *senior government reference* portfolio is assumed to be complemented by either a stronger carbon price or by an approach in which one or more flexible regulations approximate the economic incentives that would have been created by that carbon price. The latter approach is described by Jaccard et al. (2016), who find that the carbon price would have to rise to \$200/tonne CO<sub>2</sub> in 2030, in order for Canada to meet its commitment under the Paris Accord. We adopt their \$200 carbon price trajectory, assuming that, after 2030, the carbon price stays constant to 2050.

**Zero-emissions vehicle portfolio:** To this portfolio, we add the BC Zero-Emission Vehicles Act requiring that all new light-duty cars and trucks sold in the province be clean energy vehicles by 2040. We adopt the government's phased-in schedule of 10% new light-duty vehicle sales by 2025, 30% by 2030, and 100% by 2040.

**Zero-emissions building portfolio:** This portfolio includes the Zero Emissions Building Plan (City of Vancouver, 2016) that applies to both residential and commercial buildings. The plan stipulates energy efficiency improvements to the building code and, by 2030, that all new buildings must have zero-emissions space and water heating systems. In contrast, because Vancouver has not yet implemented significant policy to cause the conversion of existing buildings to zero-emissions standards, we kept the policies for existing buildings the same in this portfolio as in the reference portfolio.

### 3.3. Combining policy portfolios into scenarios

To investigate interactions between municipal policies and senior government policies, we tested all combinations of the policy portfolios described above, as shown in the matrix in Table 1. The municipal policy portfolios are listed in the first row, and the senior government policy portfolios are listed in the first column. The names of the resulting policy scenarios are given in the cells of the Table. The second row of the table combines the *senior government reference portfolio* with the *Vancouver reference portfolio* and the *Renewable City Strategy portfolio*. The middle column of the table



combines the *Vancouver reference portfolio* with each of the different senior government portfolios. The scenarios described so far include the *reference scenario* and those that test the separate impacts of the municipal policy and senior government policy portfolios. The scenarios in the other cells (last column, third row and below) test the combined impacts of these portfolios.

**Table 1: Policy scenario matrix**

	Vancouver reference	Renewable City Strategy
Senior government reference	Reference	RCS + SGRRef
Current carbon price	VanRef + \$50	RCS + \$50
Paris carbon price	VanRef + \$200	RCS + \$200
Zero-emissions vehicle	VanRef + ZEV	RCS + ZEV
Zero-emissions building	VanRef + ZEB	RCS + ZEB



## 4. The modelling results

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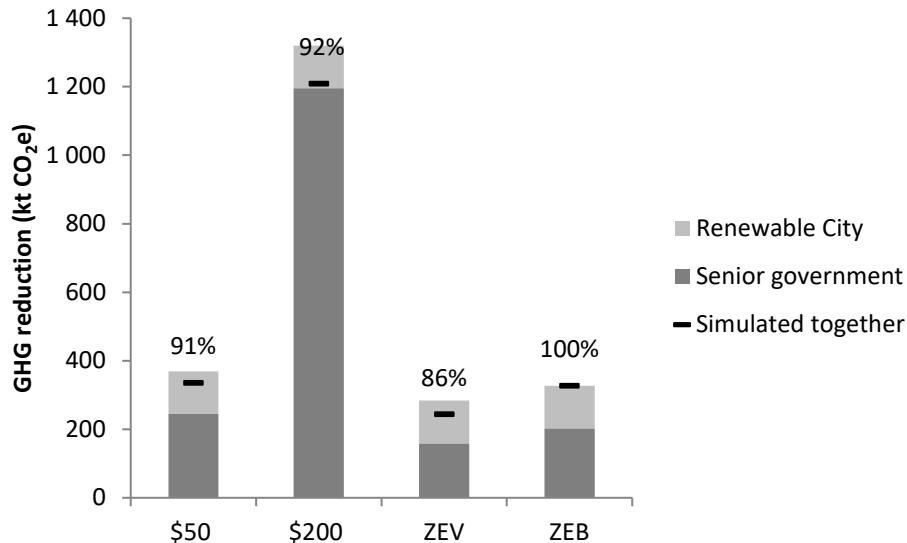
The nature of the policy interactions that occur when a municipal and a senior government portfolio are combined can be investigated in CIMS-Urban by comparing the GHG emissions reduction (relative to the reference case) when the two portfolios are simulated together with the sum of the reductions from each of the portfolios when simulated separately. In general, we expect the result when the portfolios are simulated together to be less than the sum of the separate portfolios because two policies may cause the same action and because an action resulting from one policy may reduce the impact of an action resulting from another policy.

### 4.1. Policy interactions across sectors for Vancouver

Taking into account emissions reductions from the transportation, buildings, and manufacturing sectors in Vancouver, we find that the result when the portfolios are simulated together is indeed less than the sum of the separate portfolios, generally speaking. However, the reduction from the portfolios together is almost as large (or equal to) the sum of the separate reductions for each of the combinations, as illustrated in Figure 3. This indicates that losses in emissions reduction due to policy interaction are quite small.

In Figure 3, the dark grey portions of the columns represent the emissions reductions from the senior government policy portfolio that is indicated on the horizontal axis, when this portfolio is simulated separately in CIMS-Urban. The light grey portions represent the reduction from the *Renewable City Strategy portfolio* when simulated separately (this portion is the same height across all the columns). The full heights of the columns indicate the sum of emissions reductions from the senior government portfolio and the *Renewable City Strategy portfolio*. The black bars represent the reductions from the combination of the senior government portfolio and the *Renewable City Strategy portfolio*, when simulated together. These bars are at or relatively close to the full height of the column in every case. The labels associated with the black bars express (as a percent) the ratio of the emissions reduction achieved when the policy portfolios are simulated together to the sum of the separate reductions.

According to our results, the role of municipal policy may shift based on the magnitude of the policy effort by senior government. The emissions reduction from the *Renewable City Strategy portfolio*, when simulated separately, is similar in magnitude to the reductions from the *current carbon price*, *zero-emissions vehicle*, and *zero-emissions building* portfolios, when these are simulated separately. However, under the *Paris carbon price portfolio*, the model indicates a much larger reduction. Therefore, although the loss in emissions reduction due to policy interaction between the *Renewable City Strategy portfolio* and the *Paris carbon price portfolio* is only 8%, its magnitude is almost as large as the reduction from the *Renewable City Strategy portfolio* alone.



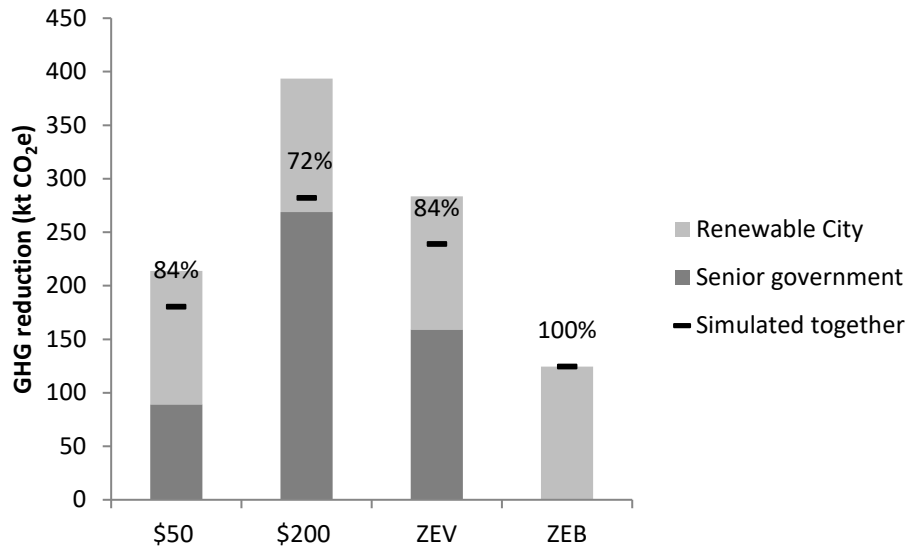
**Figure 3: Interactions between municipal and senior government policies across sectors, as revealed by GHG emissions reductions in 2050**

\$50 = Current carbon price; \$200 = Paris carbon price; ZEV = zero-emissions vehicle; ZEB = zero-emissions building

#### 4.2. Policy interactions in the personal transportation sector

Changes to urban form are believed to impact GHG emissions mostly through changes in personal transportation demand and mode choice, and these are the only actions that such changes influence in the version of CIMS-Urban used in this study. Therefore, all of the interactions between municipal and senior government policy in the current modelling exercise actually occur within the personal transportation sector. There is no policy interaction between the *Renewable City Strategy portfolio* and the *zero-emissions building portfolio* because the urban form changes caused by the *Renewable City Strategy* impact only personal transportation and not residential or commercial buildings in this version of CIMS-Urban. Taking into account only personal transportation for Vancouver, the emissions reduction from the portfolios simulated together is generally smaller than the sum of the separate reductions, indicating a greater degree of policy interaction (Figure 4).

Looking only at personal transportation, the emissions reduction from the *Renewable City Strategy portfolio*, when simulated separately, is generally larger, relative to the reductions from the senior government policy portfolios, than is the case across all sectors. Again, however, when the *Renewable City Strategy portfolio* is simulated together with the *Paris carbon price portfolio*, the loss of emissions reduction due to policy interaction is almost as large as the reduction from the *Renewable City Strategy portfolio* alone.

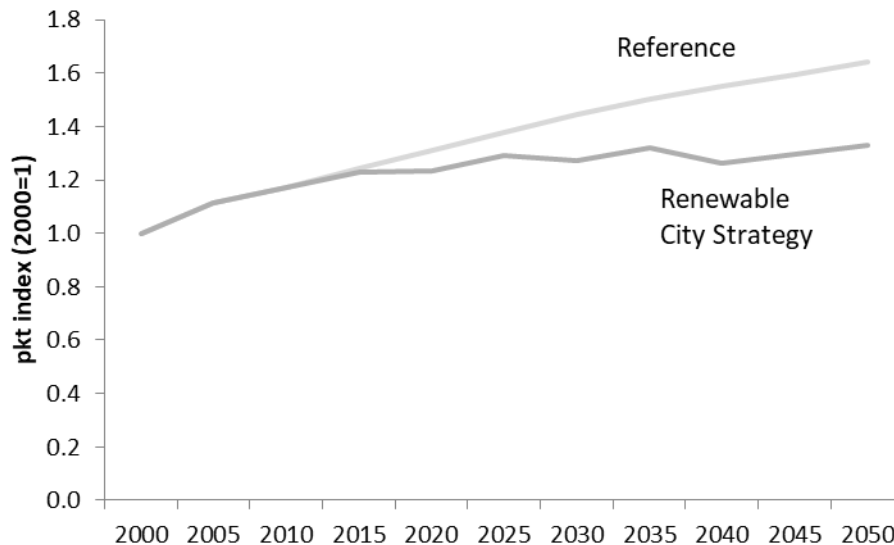


**Figure 4: Interactions between municipal and senior government policies in the personal transportation sector, as revealed by GHG emissions reductions in 2050**  
 \$50 = Current carbon price; \$200 = Paris carbon price; ZEV = zero-emissions vehicle; ZEB = zero-emissions building

### 4.3. Analysis of specific actions within personal transportation

We can learn more about the policy interactions that are occurring within the personal transportation sector of CIMS-Urban when municipal and senior government policy portfolios are simulated together by investigating the actions that occur when the portfolios are simulated separately. The categories of actions we consider here are: travel demand reduction, shifts in travel mode choice, changes in the energy sources used by personal vehicles, and changes in the energy sources used by public transit vehicles.

In the version of CIMS-Urban that we used for this project, we assumed that the only way to reduce personal transportation demand is by altering the spatial relationships between people and the locations they need to access, such as work, school, and other services. Therefore, only the *Renewable City Strategy portfolio* influences travel demand in our simulations. Figure 5 shows the evolution of personal transportation demand to the year 2050 under the reference and Renewable City Strategy scenarios.

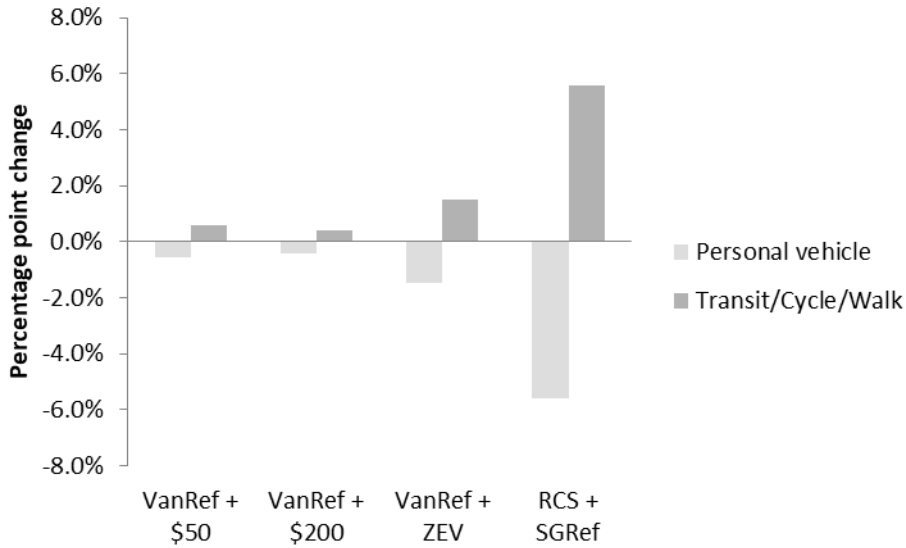


**Figure 5: Evolution of personal transportation demand**

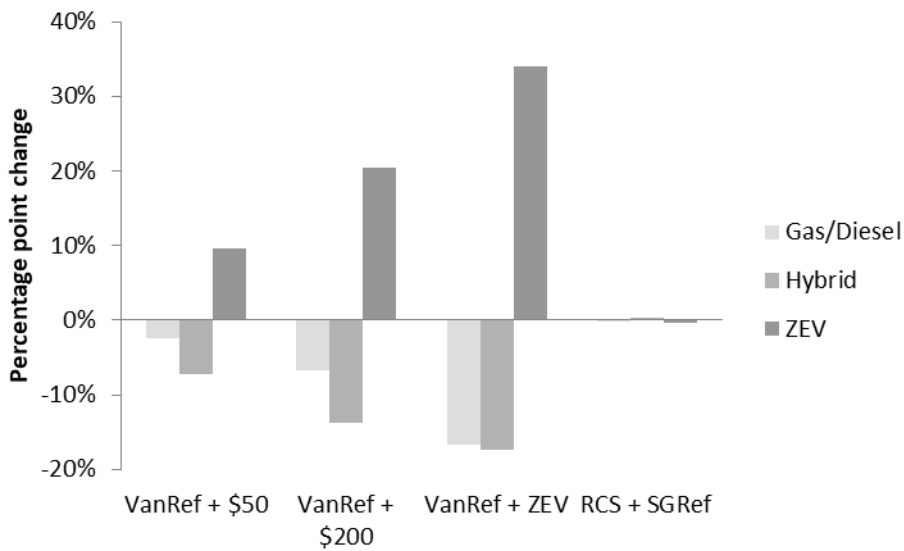
pkt = person-kilometers travelled

The mode of travel people choose in 2050 is influenced most strongly by the Renewable City Strategy in our simulations, with minimal shifts in travel mode under the senior government policy scenarios, generally speaking (Figure 6). Slightly more of a shift does occur under the zero-emissions vehicle scenario, likely due to the increased up-front costs of personal vehicles. The results suggest that preferences for travel modes are difficult to overcome, and that a more effective way to achieve a shift may be through changes to urban form that influence these preferences directly. Our modelling indicates that municipal policies and senior government policies are unlikely to have a strong interaction in terms of both causing significant mode shifts.

Personal vehicles consume different energy sources based on their motor types. As expected, the Renewable City Strategy does not have a significant influence on vehicle motor shares in our simulation. The senior government carbon pricing and zero-emissions vehicle scenarios, on the other hand, do cause a strong shift towards zero-emissions vehicles in Vancouver (Figure 7). Again here, the indication is that municipal policies and senior government policies are unlikely to have a strong interaction due to both causing the same action.

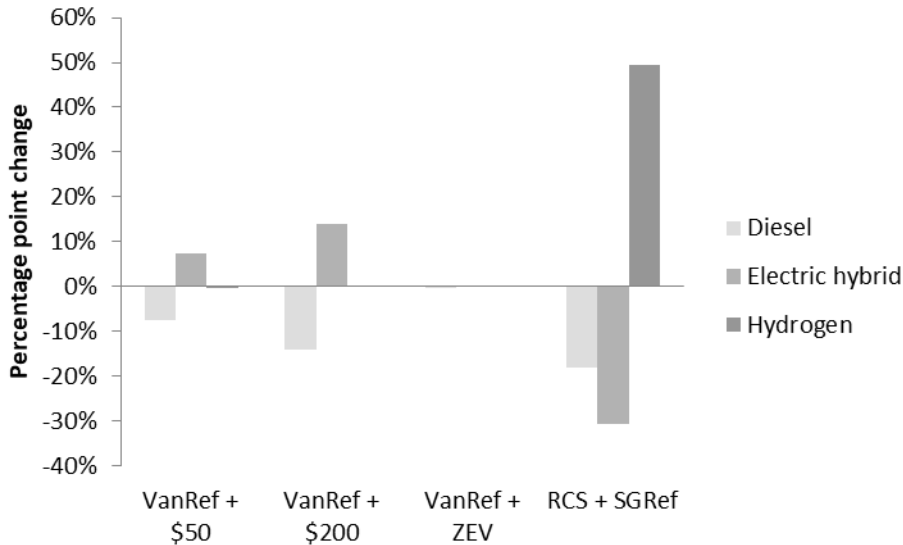


**Figure 6: Percentage point change in mode share relative to the reference scenario for the year 2050**



**Figure 7: Percentage point change in personal vehicle motor shares relative to the reference scenario for the year 2050**

The Renewable City Strategy results in a strong shift from diesel and electric hybrid buses to hydrogen buses in our simulation by 2050, due to the requirement that all public transit be zero-emissions. The senior government carbon price scenarios also influence the bus stock, with electric hybrid buses replacing diesel buses (Figure 8). Here, it appears there may be some interaction between the municipal portfolio and the senior government portfolios, with both causing a shift away from diesel buses.



**Figure 8: Percentage point change in bus shares (based on motor type) relative to the reference scenario for the year 2050**

Note: While electric trolley buses are an important component of Vancouver’s bus fleet and are expected to continue to be in the future, their contribution was not found to vary across the scenarios; therefore, they are not shown in this figure.

Our action-by-action analysis of the personal transportation modelling results for Vancouver suggests that, for the most part, municipal policy influencing urban form does not cause the same actions as the senior government policies we tested. However, a shift to zero-emissions vehicles under senior government policy can reduce the emissions reduction impact of key actions under municipal policy – namely travel demand reduction and a shift away from personal vehicles towards other modes. This is because if vehicles do not emit GHG emissions, it is not possible to reduce those emissions by reducing travel demand or switching modes. Because of this policy interaction, the emissions reduction in personal transportation from the municipal and senior government portfolios simulated together (Figure 4) is not as large as the sum of the separate reductions.





## 5. Conclusions

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We have added an urban spatial dimension to an established energy-economy model, so as to be able to simulate the interactions between policies acting at the local, sub-national, and national levels in support of Canada's energy transition. We applied this model to a series of scenarios designed to explore how policies acting on these different scales can interact to affect urban energy use and GHG emissions. Our analysis suggests that municipal policy influencing urban form does not cause the same actions as the senior government policies we tested. In particular, municipal policy has the potential to be more effective than senior government policy in promoting a reduction in the overall demand for personal transportation and a shift away from using personal vehicles to meet that demand. However, a shift to zero-emissions vehicles under senior government policy can reduce the impact of these actions on emissions. Therefore, if stringent zero-emissions vehicle mandates are implemented, the other benefits of changes to urban form, such as reduced costs of the energy transition, improvements in social equity, and enhanced livability may become more important.



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## Appendix A: CIMS-Urban in the modelling ecosystem

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### A.1. Current and past studies

CIMS has been used extensively to assess the effectiveness and costs of policies to reduce greenhouse gas emissions, both in an academic context, and for clients including governments, industry associations, and non-governmental organizations. Beginning in 1999, CIMS was one of the four main models employed by the Canadian government in the national consultation process to meet Canada's international greenhouse gas emissions reduction commitments (e.g. Energy Research Group / M.K. Jaccard and Associates, 2000; M.K. Jaccard and Associates, 2003; M.K. Jaccard and Associates, 2007). CIMS has also been represented at the Energy Modeling Forum (EMF) at Stanford University (e.g. Murphy and Jaccard, 2011).

Energy Research Group / M.K. Jaccard and Associates, 2000. Integration of GHG Emission Reduction Options using CIMS. Prepared for the Analysis and Modelling Group of the Climate Change National Implementation Process.

M.K. Jaccard and Associates, 2003. Construction and Analysis of Sectoral, Regional and National Cost Curves of GHG Abatement in Canada (Part IV: Final Analysis Report). Prepared for the Office of Energy Efficiency, Natural Resources Canada.

M.K. Jaccard and Associates, 2007. Cost Curves for Greenhouse Gas Emission Reduction in Canada: The Kyoto Period and Beyond (Final Analysis Report, Enhanced Costing Indicators). Prepared for the Office of Energy Efficiency, Natural Resources Canada.

Murphy, R., Jaccard, M., 2011. Modeling efficiency standards and a carbon tax: simulations for the U.S. using a hybrid approach. *The Energy Journal* 32(SI), 43–60.

[http://www.emrg.sfu.ca/media/publications/Murphy&Jaccard\\_EMF\\_US\\_Policy\\_Simulations\\_EnJournal\\_2011.pdf](http://www.emrg.sfu.ca/media/publications/Murphy&Jaccard_EMF_US_Policy_Simulations_EnJournal_2011.pdf)

Development of CIMS-Urban began in approximately 2015. In a 2017 public report (Zuehlke et al., 2017) and 2019 academic article (Jaccard et al., 2019), the model was used to assess the potential of cities to achieve deep reductions in GHG emissions through a shift to renewable energy, based on a case study of Vancouver. The authors found that, while cities like Vancouver have some important options for reducing energy use by their inhabitants, they may lack the authority to completely transform the energy system. To achieve such ambitious energy and GHG targets, cities with jurisdictional powers comparable to those of Vancouver are dependent to some degree on complementary GHG and energy policies from senior levels of government.

Zuehlke, B., Jaccard, M., Murphy, R., 2017. Can Cities Really Make a Difference? Case Study of Vancouver's Renewable City Strategy. *Energy and Materials Research*



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Jaccard, M., Murphy, R., Zuehlke, B., Braglewicz, M., 2019. Cities and greenhouse gas reduction: policy makers or policy takers? Energy Policy 134, 110875. <https://doi.org/10.1016/j.enpol.2019.07.011>

## A.2. Possible future studies

### **Explore the impact of an alternative method of estimating behavioral parameters**

Over the next year, we will be applying survey techniques to learn more about the effectiveness of two kinds of policies that have an impact at the urban scale: home energy retrofit incentives and transportation network improvements. The surveys will sample thousands of individuals in cities across Canada. Participants will be presented with hypothetical choices about personal transportation and home energy retrofits under varying conditions. Their responses will be used to develop discrete choice models that will inform the behavioral parameters in CIMS-Urban. We have funding in place and the surveys are in the late development stage. A possible extension to the current project would be to update the results in light of new information obtained from these surveys.

### **Extend the analysis to Metro Vancouver**

We are currently expanding the Vancouver version of CIMS-Urban to encompass all of Metro Vancouver. This will allow us to simulate multi-city commuting behavior. The next applications to large metropolitan regions will be for Toronto and Montreal.

### **Apply urban modelling tools to cities of different sizes**

CIMS has recently been used to model energy and emissions in Victoria and Nanaimo (BC). Our plan is now to expand the scope of our urban modelling tools by embedding standardized city archetypes within them. In future work, we will explore how differences between provinces, as well as differences in the size or population density of a city affect its potential for energy transition.

### **Investigate a greater range of impacts and benefits of policies**

There is interest in the potential to use CIMS-Urban to investigate a greater range of impacts and benefits of policies. This could include, for example, investigating the livability and equity implications of changes in land use and public transportation infrastructure in urban areas.

## A.3. Possible synergies with other models

The potential of CIMS-Urban can be enhanced by pursuing synergies with other models. CIMS-Urban can both inform and be informed by complementary models. A case study of how this could occur is our proposed collaboration with our partners at ElementsLab,



a research group in UBC's School of Architecture and Landscape Architecture. ElementsLab applies a set of tools including GIS, building and community-scale energy models, and a procedural tool for generating 3D urban form. These tools are combined in a process to simulate energy, emissions, and social metrics at neighbourhood and community scales. Working with our colleagues, we have developed two possible approaches to integrating CIMS-urban with the tools developed by ElementsLab.

### **Soft-linking to enhance the physical representation of buildings in CIMS**

In developing CIMS-Urban, we have advanced the representation of spatial determinants of personal transportation demand and mode choice. However, we do not anticipate capturing all of the physical aspects of buildings that are taken into account in some urban-scale models, including those developed by ElementsLab. Heating and cooling requirements in CIMS are a function of floor space, the building type (single family detached, townhouse, apartment), and the efficiency of the building envelope. This level of detail is well-suited for calibrating and running most of the forecasts that fall within our modelling scope. However, a higher level of detail could be helpful in order to simulate changes to building codes at the community level. Other policies of interest to municipal (and possibly other levels of) government, such as laneway housing, rooftop solar, and neighborhood design could also benefit from a more spatially disaggregated approach. Therefore, we are interested in soft linking CIMS with ElementsLab models to simulate policies that affect the structure, placement, and environment of buildings.

### **Use of CIMS-Urban to help develop scenarios for ElementsLab**

A key component of the research at ElementsLab is the development of scenarios (more specifically, portfolios of complimentary strategies) that can be simulated spatially, generating new urban forms and associated metrics of performance. A challenge when generating these scenarios is anticipating the broader policy and economic contexts that may dictate the appropriate strategies for a given circumstance. Our colleagues at ElementsLab believe that better integration with CIMS could provide them with both the economic and policy rationale for their scenarios, and an aggregate set of assumptions they can downscale and spatialize to their more local conditions.