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Meeting the climate change challenge: a scan of greenhouse gas emissions in BC communities

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The Canadian province of British Columbia (BC) is taking significant steps towards climate change mitigation, including a carbon tax on fossil fuels and legislation that mandates greenhouse gas (GHG) reductions within public sector organisations and GHG reduction targets for municipalities. This paper carries out a preliminary scan of the GHG emissions of BC communities using the provincially mandated Community Energy and Emissions Inventory reports. We map trends in energy consumption and emissions *per capita* while uncovering correlations between these variables and land-use planning, geographic, and demographic variables. These data have shown that: (1) energy consumption in BC is an adequate proxy for GHG emissions; (2) transportation, more than buildings, is a strong driver of overall GHG emissions; (3) building emissions are not likely to be strongly influenced by dwelling type, but density of buildings is crucial; (4) geographic location influences emissions; and (5) population size and age do not appear to influence *per capita* emissions. These findings are particularly important as they suggest that the potentially intransigent factors of income and population size need not be barriers to achieving significant GHG reductions. The policy onus thus falls squarely on transportation planning, land-use, energy conservation, and fuel switching. This in turn highlights the importance of deeper underlying sociocultural and political preferences, which shape the behaviours that have a strong bearing on emissions profiles.

Keywords: climate change; greenhouse gas emissions; communities; transitions

1. Introduction

Global climate change, exacerbated by anthropogenic greenhouse gases (GHGs), poses an immediate and serious threat to both the ecological integrity of Earth's biosphere and the social and economic stability of society (Stern 2006, IPCC 2007). Success in addressing climate change at the international level has been mixed; though some countries have responded to their Kyoto protocol commitments and others, Canada included, have not met their Kyoto goals. Indeed, the Canadian government formally withdrew from the

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Kyoto protocol in December of 2011. Whether or not their respective national governments are taking strong action, many local governments are working independently to address climate change within their own jurisdictions (Schroeder and Bulkeley 2009, Bulkeley and Castan Broto 2013). Cities may also use climate change to pursue related objectives, such as sustainable urbanisation, energy efficiency, and renewable energy production (Romero Lankao 2007), and provide a context within which both behavioural and technical innovations may arise and spread (Dodman 2009).

British Columbia (BC) is on the leading edge of a major wave of local innovation to address climate change in Canada. The province has introduced climate change policies that go far beyond those in other North American jurisdictions. These include a carbon tax on fossil fuels and a requirement for all public sector organisations to be carbon neutral by 2010 and to buy offsets if these goals are not met (Province of British Columbia 2008). These policies have created a unique research opportunity: the province is a "living laboratory" of policy innovation for both climate change adaptation and mitigation at the municipal and regional contexts.

The scale of the challenge is significant, both in terms of the quantity of emissions that municipalities aim to reduce and the complexity of strategies required to adapt to climate change, as well as the challenges presented by path dependence (or inertia), policy incoherence, and widely varying levels of public support for change. This paper tackles the first element of this challenge by evaluating a unique pool of data: the Community Energy and Emissions Inventories (CEEI) produced by more than 150 municipalities in the Canadian province of BC. We explore correlations between community emissions patterns and high-level demographic data, in order to understand the role that relative geographic remoteness and climate play in determining emissions trajectories in these communities and speculate about lessons that high emissions communities might learn from their lower emissions counterparts. We also examine the ways in which these sources of emissions may or may not be under the direct jurisdictional control of municipalities and explore the behavioural and institutional enablers of action in these areas. Ultimately, this paper lays the foundation for an exploration of climate change action that may occur in BC, in the context of a strong provincial mandate for mitigation and growing momentum behind community-scale innovation.

2. Community GHG emissions: sources, measurement challenges, and mitigation dynamics

As the massive rural to urban migration continues, cities (and communities, more broadly) are increasingly becoming the focus of efforts to trigger sustainability transitions (Nevens et al. 2012) and manage the causes and consequences of climate change (Betsill and Bulkeley 2006). More than 6000 cities around the world have declared GHG emissions reduction targets (Hoornweg et al. 2011) and networks are springing up to share best practices (Betsill and Bulkeley 2004).

A number of trends are emerging in the context of urban GHG emissions, both in terms of sources of emissions, and the challenges associated with measuring them. Traditionally, GHG emissions from industrial operations in cities have dwarfed all other sources, but these activities are increasingly being pushed to the fringes of large urban areas (Dodman 2009) or into smaller cities, and developing or rapidly industrialising countries. Transportation-related emissions are increasing as a proportion of overall emissions and urban density is one of the most important factors influencing the amount of energy used in private passenger transport (Dodman 2009). Combining the de-industrialisation trend with reduced dependence on single-occupancy vehicles possible in dense urban areas, it would be unsurprising to find higher emissions *per capita* in small cities compared to some larger ones.

While the Intergovernmental Panel on Climate Change has developed a protocol for GHG inventories that has emerged as the single standard for country-level emissions, there is no harmonised approach to GHG inventories in communities (Ibrahim et al. 2012). The smaller the scale, the more challenging the boundary issues associated with GHG inventories (Kates et al. 1998) and there are practical implications of the GHG inventory model that is followed. In service-oriented cities, for instance, emissions from consumption activities matter significantly more than emissions from production (Bai 2007), since production is located elsewhere, transferring the burden of these emissions to a different jurisdiction (and in many cases a different country). Even so, the production-based estimations of GHGs are by far the most common and this is the approach taken in the CEEI prepared by the BC Government and described in this paper (with the exception of emissions calculated from waste). A production *vs.* consumption (or ecological footprint) model suggests very different reduction strategies, including different regulatory bodies, engagement campaigns, and infrastructure projects. For this reason, blended production/consumption inventory methods are often recommended at the urban scale, to account for emissions (such as from electricity generation or waste decomposition) that occur outside the city's boundaries (Ibrahim et al. 2012).

Once robust inventories are created (regardless of where the boundaries are set and whether they are production or consumption-based), the issue becomes one of *governing* these emissions. Cities exist within a complex jurisdictional web of interdependences, highly influenced by decisions made by other levels of governments, coalitions of actors, and individual decision-making. Capacities (technical, financial, human, and institutional) also vary from city to city, adding further complexity to the question of how to stimulate and sustain effective GHG management.

Moreover, the politicians, planners, engineers, and other practitioners who influence both GHG emissions and vulnerability are part of a complex web of human/environment interactions, political and economic trajectories, and public values that deeply shape the suite of available policy responses to climate change and their likely success. Even so, the innovative GHG management strategies have sprung up across the province of BC. The provincially mandated CEEI process partially tracks the effectiveness of these strategies and the evidence of emissions trajectories will emerge as annual data accumulate. Before delving into this data, however, we will first trace the evolution of multi-level governance of climate change in BC.

3. Provincial climate change legislation in BC

The province of BC has taken a series of significant steps towards triggering GHG mitigation (and, more recently, adaptation). This transition towards leadership on climate change began in 2007 with a high-level statement of provincial mandate, which in BC was presented through a "speech from the throne" (Pembina Institute 2009). A revenue neutral carbon tax on fossil fuels was introduced, but was confronted by a significant public and political backlash. The most common complaints pertained to the fear that the carbon tax would unfairly penalise remote and northern communities, both of which may require additional fuel for transportation and heating than more urban communities in milder climates.

While the carbon tax is broadly applied, the BC Government has also implemented legislation and programmes to support municipal action on climate change. The BC *Local Government Act* was revised (Bill 27) to require that each municipal government adopt targets, policies, and actions for the reduction of GHG emissions in their Official Community Plans. The Climate Action Charter, an initiative between Union of BC Municipalities and the BC Government included voluntary commitments by municipalities to become carbon neutral in their operations by 2012, measures and reports on their community GHG emissions and creates complete, compact, and energy efficient communities.

In order to enable BC municipalities to track progress against their GHG targets, the Government of BC established an emissions baseline for BC municipalities the CEEI. In the sections that follow, we analyse the data generated through these inventories to explore: (1) correlations between GHG emissions and geographic and demographic variables and (2) potential pathways that municipalities might follow to significantly lower emissions in the next 20–50 years.

4. Methods

The CEEI is an ongoing effort by the Government of BC to generate periodic inventories of energy consumption and GHG emissions for municipalities and regional districts in BC. The inventories include GHG emissions from on-road transportation, buildings, and solid waste. Estimates of land-use change from deforestation activities and enteric fermentation from livestock in the agricultural sector are also available at the Regional District level. For a detailed review of the methodologies and scope of CEEI, see the BC Ministry of Environment's emissions inventory guidance document (BC Ministry of Environment 2010). These data were gathered for the year 2007 and released by the province in 2010.[1] Table 1 gives a summary of the data collected and the source or method of collection.

A subsequent set of CEEI data has been released for BC municipalities for 2010; however, the version available at the time of this analysis included errors for some communities (see below), which the BC Government was working to correct.

4.1. Data collection

A spreadsheet was created for the 28 regional districts and 168 municipalities in BC. A range of variables was compiled for each entry from the 2007 CEEI and a number of other sources. We do not know the exact nature of the errors that the BC Government has corrected. It is possible to identify likely errors in the data set by identifying unreasonable results. These "extremes" were noted in several of the data sets ($n<5$) and we do not believe would result in a significant impact on the results. There may also be unknown errors, confirming our intent to replicate this analysis with subsequent data releases. Table 1gives a complete list of the data collected and its sources.

A number of additional variables were also generated from the data given in Table 1. These additional variables, the method of derivation, and their relevance are given in Table 2.

4.2. Analysis

Our aim was to investigate potential relationships between demographic/geographic variables and GHG emissions using the data set at the level of a scan; we were not intending to undertake a detailed or comprehensive analysis. A "scan" may be viewed as a high-level analysis of broad trends in the data based on a restricted set of causal or correlational variables that may reveal particularly salient features in the data, highlighting issues that warrant deeper analysis. The variables were selected through an expert consultation

Table 1. Data source and collection methods employed in the analysis of CEEI in BC.

Data	Source/method	Variables
Contact information	Civic Info BC provides contact information for local government senior officials and staff	Eight fields such as Chief Administrative Officer, phone and fax number, email, and address
Population statistics and projections	BC Stats estimates local government populations in 2006 and 2009. For regional districts, population estimates are projected into the future (2006–2036) using a cohort-survival method	Population (2006 and 2009) Projected population (2016, 2026, and 2036)
Economic and social statistics	Statistics Canada provides community profiles in the 2006 Census of Population. The economic and social statistics were selected from a longer list of community-level information	Per cent of people over 65; unemployment rate; average income; average rent; persons paying over 30% of their income on shelter; and average dwelling value
GHG emissions and energy data	The CEEI Reports, developed by the BC Climate Action Secretariat and the BC Ministry of Environment, estimate community-wide energy consumption and GHG emissions from on-road transportation, buildings, and solid waste. The method to quantify energy consumption and GHG emissions is detailed in BC Ministry of Environment (2010)	Private and commercial vehicles; Residential and commercial buildings; Solid waste; and Total GHG emissions
Residential land-use statistics	Dwellings are broken down into eight structural dwelling types: single detached house, semi-detached house, row house, duplex, apartment > five stories, apartment <five stories, other single attached house and movable dwelling. Relative to single detached housing, higher density neighbourhoods are associated with lower energy consumption and shorter driving distances	Dwelling type (categories by %); net land area; area of national parks, provincial parks, local parks, agricultural land reserve
Commute to work	There are eight modes of commute: vehicle as driver, vehicle as passenger, public transit, walked, bicycle, motorcycle, taxicab, and other method. Modal shifts towards alternative transportation such as walking and public transportation reduces GHG emissions. Commute distance is separated into five categories: less than 5 km, 5–9.9 km, 10–14.9 km, 15–14.9 km, 15–24.9 km, 25 km, or more. High-density neighbourhoods near employment centres are associated with shorter commute distances	Trips by vehicle type (%); Commute by distance (%); Average trip length for commuting
Residential density	Residential density is calculated by dividing the total population by the community's net land area (ha). Net land area excludes areas that are assumed to be undevelopable: Crown land, parks, Indian Reserves, water features, airports, ALR, and waste disposal sites	Density of dwellings

(*Continued*)

Table 1. Continued.

Data	Source/method	Variables
Greenspace	Includes the total area of national parks, provincial parks, local government parks, and Agricultural Land Reserves compared to the total area of other community land uses	Area of national parks, provincial parks, local parks, and Agricultural Land Reserve
Residential energy	Energy consumption (GJ) and GHG emissions (tCO_2e) from residential dwellings are subcategorised into five energy sources: electricity, natural gas, heating oil, propane, and wood	Residential building fuel consumption and GHG emissions by fuel type
Commercial energy use	Energy consumption (GJ) and GHG emissions (tCO_2e) from residential dwellings are subcategorised into three energy sources: electricity, natural gas, and propane	Commercial building fuel consumption and GHG emissions by fuel type
Building energy use	Energy consumption (GJ) and GHG emissions (tCO_2e) from residential and commercial buildings are aggregated and subcategorised into five energy sources: electricity, natural gas, heating oil, propane, and wood	Residential and commercial building fuel consumption and GHG emissions by fuel type
Private vehicle energy and emissions	Sum of the Energy consumption (GJ) and GHG emissions (tCO_2e) from small passenger cars, large passenger cars, light trucks, vans, and SUVs. Excludes energy and emissions from commercial vehicles, tractor trailer trucks, motor homes, buses, and motorcycles	GHG emissions and fuel consumption by vehicle type
Transportation fuel use	Transportation energy consumption (GJ) and GHG emissions (tCO_2e) from on-road transportation are subcategorised into three fuel types: gasoline, diesel, and other fuel. All vehicles that are licensed for use on public roads are included (i.e. small passenger cars, large passenger cars, light trucks, vans, SUVs, commercial vehicles, tractor trailer trucks, motor homes, buses, and motorcycles)	GHG emissions and fuel consumption by fuel type
Total energy and emissions	Energy consumption (GJ) and GHG emissions (tCO_2e) from residential buildings, commercial buildings, and transportation are summed. GHG emissions resulting from solid waste disposal are also added to the tCO_2e total. These GHG emissions are released with the decomposition of municipal solid waste over time and the combustion of solid waste in incineration facilities. Each local government is attributed with solid waste GHG emissions based on their volume of solid waste irrespective of where the landfill site is located	Total GHG emissions by source (transportation, buildings, and waste)
Per capita energy and emissions	Total energy consumption (GJ) and GHG emissions (tCO_2e) are divided by 2009 population estimates to generate *per capita* figures	*Per capita* GHG emissions by source (transportation, buildings, and waste)

Table 2. Additional variables derived from the data given in Table 1.

Variable	Method	Relevance
GHG emissions *per capita* (for buildings, transportation, waste, and total)	GHG emissions were divided by population for each municipality and regional district	Population is a key variable in determining total municipal GHG emissions
VKT	Fuel efficiencies were assumed for each vehicle type. Total fuel consumption was divided by fuel efficiency and number of vehicles by vehicle type from CEEI to generate VKT per vehicle	VKT is influenced by land-use patterns and behaviour and in turn is a key source of community-wide GHG emissions
Population density	Total population was divided by net area of the municipality or regional district. Net area was calculated by subtracting parks and agricultural reserve	Population density can influence the distance people are from key services and the distance that they will drive

process that included both climate change mitigation and sustainability researchers in the province as well as individuals from the Provincial government who were responsible for gathering the CEEI data. As a result, we employed two simple strategies to investigate potential relationships: visualisation and correlations.

The CEEI data were uploaded into Many Eyes, an open source, online software developed by IBM. Many Eyes is roughly modelled on well-known participatory sites such as Flickr and YouTube (for a more detailed description, see: Viégas et al. 2007). Central activities on the site are to upload data, construct visualisations, and leave comments on either data sets or visualisations. Data are uploaded in a series of columns and then a visualisation strategy is selected. The three different visualisations that were used for this data set included the block histogram, the bubblechart, and the scatterplot.

A simple statistical analysis was completed in Microsoft Excel to complete a best fit correlation analysis between data series that we identified as having potential correlations. Microsoft Excel is not the most sophisticated statistical software but because the analysis was limited to a simple regression and the data were compiled in Excel, it was deemed adequate for this task. More detailed and complex analysis could be applied including the non-linear and multivariate regression analysis to more fully investigate the relationships between the data.

Geographic information systems analyses were completed to identify geographical trends in the data, what we have termed as clustering analysis. Clustering analysis is the visualisation of data on a landscape or map. This enables us to consider the relationship between geography and spatial characteristics of geography such as climate and population centres against variables analysed in the study. The two data sets analysed included the GHG emissions *per capita* for private vehicles (Figure 5(a)) and for residential buildings (Figure 5(b)). This data was presented at the level of Regional Districts so that a colour-coding strategy would be evident at the Provincial level. Because municipalities are small, the data would have otherwise appeared as dots and the colour coding would not effectively convey patterns. Because of the data available, however, we decided to test all of the correlations for which the existing literature on drivers of GHG emissions might suggest some result.

5. Community GHG emissions in BC

5.1. Geographic and demographic correlates with community GHG emissions

Analysis of the CEEI data, when paired with the geographic and demographic data listed above, yields five core insights: (1) energy consumption in BC is a strong proxy for GHG emissions; (2) transportation, more than buildings, is a strong driver of overall GHG emissions in the province; (3) building emissions are not likely to be strongly influenced by dwelling type, but density of buildings is crucial; (4) geographic location influences emissions; and (5) population size and age do not appear to influence *per capita* emissions. Each of these will be addressed below. Note that *p*-values for all of the correlations below were significantly lower than 0.05, indicating that probability that this data would have arisen due to chance is extremely low.

5.1.1. Energy consumption as a proxy for GHG emissions

There is a very strong positive correlation between total energy consumption (GJ) in a community and total GHG emissions (tCO_2), with the correlation explaining 98% of the variation (Figure 1). While some degree of correlation is to be expected because GHG emissions are derived from energy consumption, the closeness of the relationship is not given because of the varying GHG intensity of different sources of energy for transportation and buildings in BC (for example, hydro electricity is close to carbon neutral). This finding suggests that the overall energy use is in fact a good first-order proxy for overall GHG emissions in BC communities, meaning that it is not necessary to calculate the GHG emissions for a community: energy consumption provides a good indication of what the GHG emissions will be.

5.1.2. The influence of transportation on overall GHG emissions

Transportation GHG emissions demonstrate stronger correlations (88%) with total GHG emissions than building-related GHG emissions (49%) (Figure 2(a) and 2(b)). As can be seen from the two figures below, building emissions are bunched at the lower end of their range. Transportation emissions are thus a much better proxy for overall emissions in BC municipalities. Building emissions are discussed in greater detail in the section that follows.

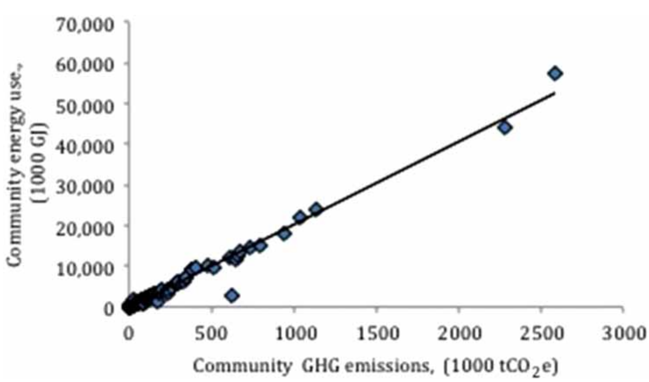

Figure 1. Total energy and total GHG emissions illustrating a strong positive correlation between total energy consumption and total GHG emissions. tCO_2 refers to tons of carbon dioxide equivalent.

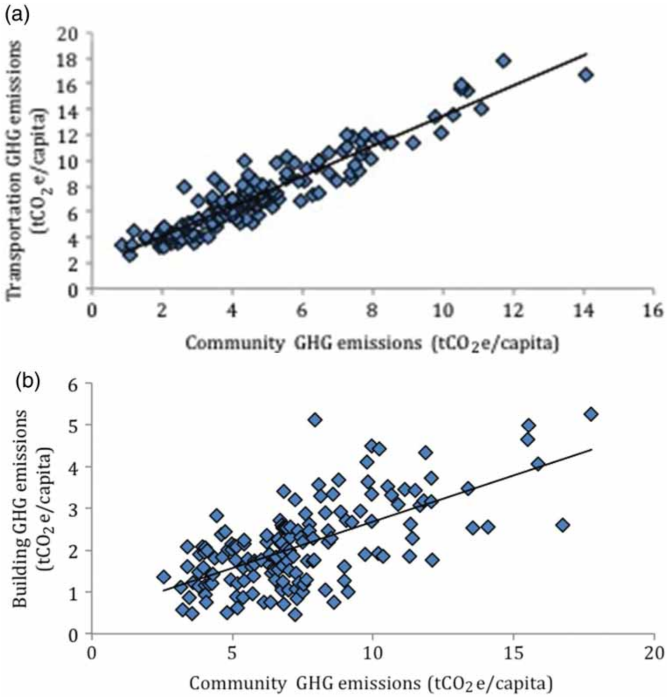

Figure 2. (a) Illustrates transportation GHG emissions *vs.* total GHG emissions and (b) shows building GHG emissions *vs.* total GHG emissions. Transportation GHG emissions demonstrate stronger correlations with total GHG emissions than building-related GHG emissions. tCO_2 refers to tons of carbon dioxide equivalent.

This finding highlights the crucial importance of the jurisdictional challenges that municipalities face, mentioned earlier in this paper. Transportation emissions are influenced by a number of factors, including the availability and efficiency of public/mass transit systems (modal mix), the form and function (i.e. density and location of services) of communities, and cultural variables that shape the uptake of more efficient or smaller vehicles (or increased car ownership resulting from economic growth, or the status associated with vehicle ownership). Policy tools that aim to reduce transportation-related emissions can range from fiscal tools, such as clean energy subsidies or carbon taxes, to regulatory tools, such efficiency standards and vehicle occupancy standards (Timilsina and Shrestha 2008). The palatability and uptake of these tools, however, will vary depending on a host of factors (including municipal political culture, constituents' perception of the problem, public preferences and political leanings, and the broader socio-economic context). Jurisdiction over the majority of these tools, furthermore, rests with either provincial or federal governments, rather than at the municipal level. Even so, the emissions from transportation are also shaped by municipalities' land-use planning: the proximity of residents to commercial districts, schools, and recreation. While deeper analysis of the specific drivers of transportation emissions in each municipality is required to determine which suite of policy tools might be most effective, it is clear that municipalities do not always have direct control over many of them.

5.1.3. Dwelling type and density

Most municipalities in BC have a density of under three people/ha. In contrast, Vancouver has a density at 62.9 (people/ha), followed by Victoria (47.7 people/ha), New Westminster and North Vancouver (46 people/ha), and White Rock (39.8 people/ha). The low levels of density are reflected by the dwelling mix in BC municipalities, with single-family homes making up between 60% and 70% of the dwelling mix in most communities. The communities with the highest proportion of row houses are Whistler (21%), Port Moody (23%), and Pemberton and Port Alice (both 29%). The small populations of these communities and in some cases their rural nature mean that a relatively high proportion of attached dwellings is unexpected, a form of built environment we associate more commonly with urban areas.

The correlation between type of dwelling and residential GHG emissions was very weak (Figure 3). This somewhat surprising result suggests that residential emissions are more likely influenced by fuel mix (as shown in Figure 1) than by type of dwelling. In other words, density is a far weaker driver of residential GHG emissions than the types of fuel used to heat and power the home. This highlights the importance of the building code – a regulation developed by the province (with the exception of the City of Vancouver, which is empowered to develop its own building code). Building codes may designate a particular mix of fuels, require levels of efficiency or emissions that implicitly require fuel switching, or support the connection to district energy systems that foster a reduced reliance on fossil fuels. Municipalities do, however, possess tools aside from the building code that may impact the fuel mix used to heat and power homes. District energy systems and the bylaws requiring commercial and private residences to connect to them may be designed and implemented by municipalities. This has occurred in the City of North Vancouver, Surrey, and Revelstoke (for instance).[2]

Density shows a very weak negative correlation with commuting trips by vehicle as either a driver or a passenger, with Vehicle Kilometres Travelled (VKT)[3] and with residential energy consumption, all of which are unexpected findings (Figures 4(a)–(c)). The weakness of these correlations suggests that other important variables are at play, which might include walkability, accessibility to public transit, and cultural norms related to driving or others. Further investigation is needed to better understand this result.

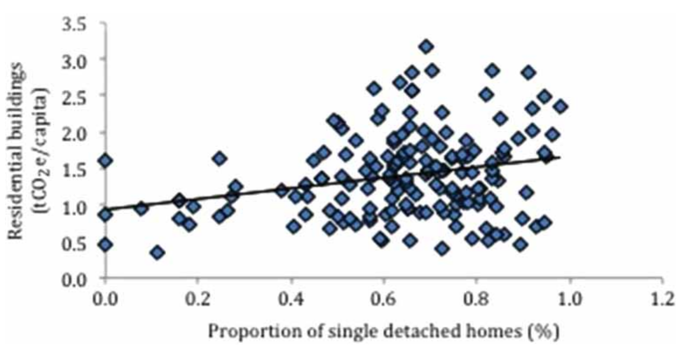

Figure 3. Single-family homes and residential GHG emissions. The correlation between type of dwelling and residential GHG emissions was very weak. tCO_2 refers to tons of carbon dioxide equivalent.

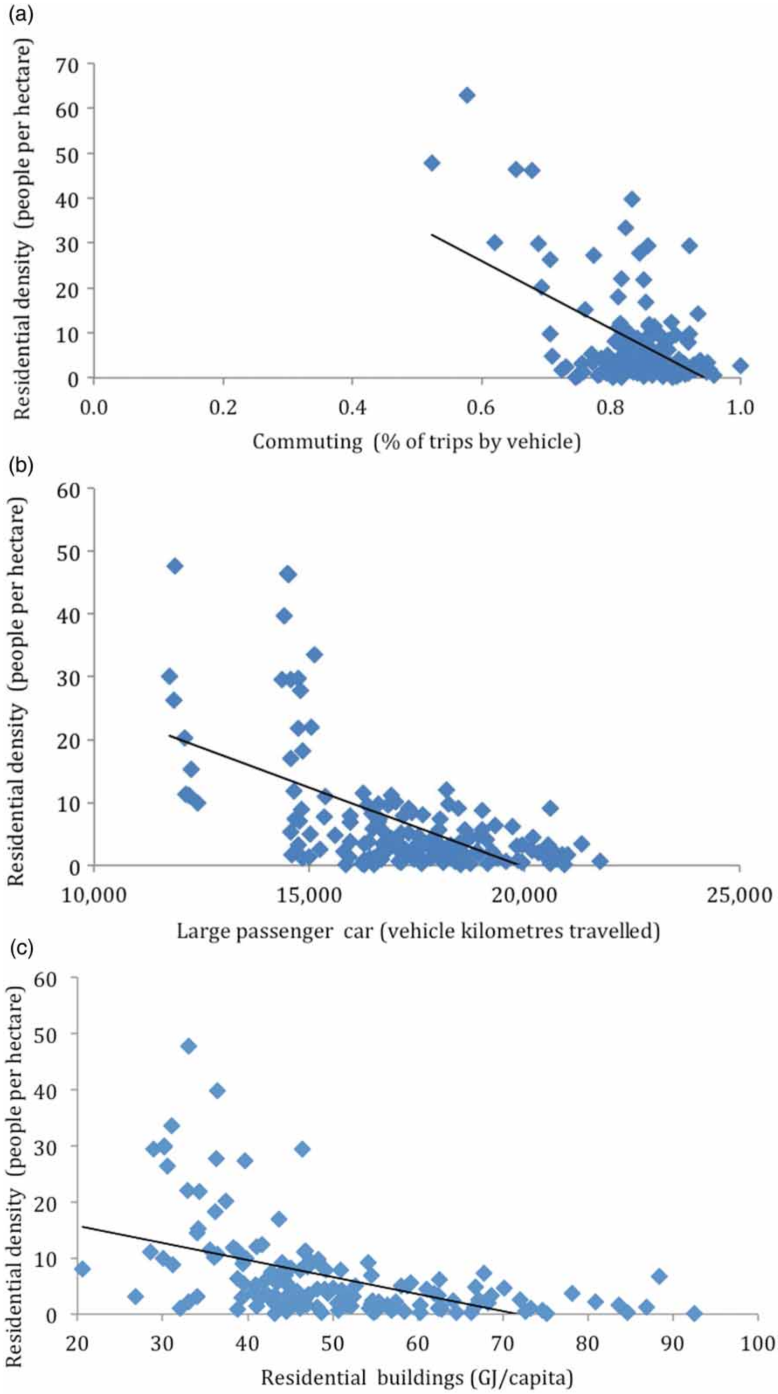

Figure 4. (a) Density and commuting; (b) Density and distance driving; and (c) Density and residential energy consumption. Density shows a very weak negative correlation with commuting trips by vehicle as either a driver or a passenger, with VKT and with residential energy consumption, all of which are unexpected findings.

5.1.4. Geographic location is correlated with emissions

The analysis considered the influence of geographic location, in particular the effect of climate on the community GHG emissions and the remoteness of the community, which could result in longer vehicular trips and as a result increased GHG emissions. The clustering analysis illustrates the likely impacts of climate on residential energy consumption and GHG emissions. This is not a definitive analysis as a simple assumption was made that more northerly locations would be colder and thus requires a larger heating load. Figure 5(a), for instance, shows that *per capita* GHG emissions from residential dwellings increase as one moves east and north within the province, but not perhaps as clear a relationship as one would expect. Regional districts in the mid-western parts of the province are within the same range of residential GHG emissions as regions in the south-west. Transportation GHG emissions show a stronger pattern of increase towards first rural regions and second northerly regions (Figure 5(b)).

Hudson's Hope in northern BC has the highest VKT (15,500 km/car), whereas Esquimalt, Victoria, Sooke, Metchosin, and Colwood are clustered around 10,000 km/car. VKT for larger passenger cars increases to between 16,000 km/car and 20,000 km/car. Fort St. James has the highest VKT for large cars (21,765 km/car). Interestingly, larger cars drive further than small cars, despite increased fuel consumption. This finding is possibly because larger vehicles are required for the sorts of tasks and winter road conditions that are more common in remote, Northern, and rural communities in BC. Furthermore, resource-based employment, such as forestry and oil and gas, is more common in central and Northern BC, requiring residents to drive long distances using larger vehicles.

5.1.5. Limited influence of population size and age

These analyses showed that there is no notable correlation between community population size (as measured by number of households) and *per capita* GHG emissions, indicating that it is as possible for a small community to have low *per capita* GHG emissions as a large community (Figure 6(a)). Indeed, a number of the communities with the lowest *per capita* GHG emissions are rural with small populations including Sooke, Oak Bay, Bowen Island, Lions Bay, Saanich, and View Royal. All of these are, however, located in the south-west corner of the Province. No meaningful correlation was found between age and VKT or between income and GHG emissions (Figure 6(b)–(c)). This is surprising given that one might expect those with higher incomes to have larger homes or more consumptive vehicles. One possible explanation for this is that the Metro Vancouver region contains residents with some of the highest incomes in the province, but also offers significant density, active/public transportation options, and GHG mitigation initiatives (such as district energy systems and landfill gas recovery).

5.2. Outliers

A number of communities were removed from the regression analysis because they were clearly outside of the trend, but there is an opportunity to learn from these outliers. For example, the Town of Gibsons has a population of 4200 but has a relatively high density of 11.2 people/ha and an extremely low vehicular commuting rate of 19.5%. One possible explanation lies not in Gibsons' high level of density but in its geographic proximity to water; most people in Gibsons travel to Vancouver for work via a 40-minute ferry and bringing a vehicle on this ferry is expensive. If so, this could be an indicator that sufficiently

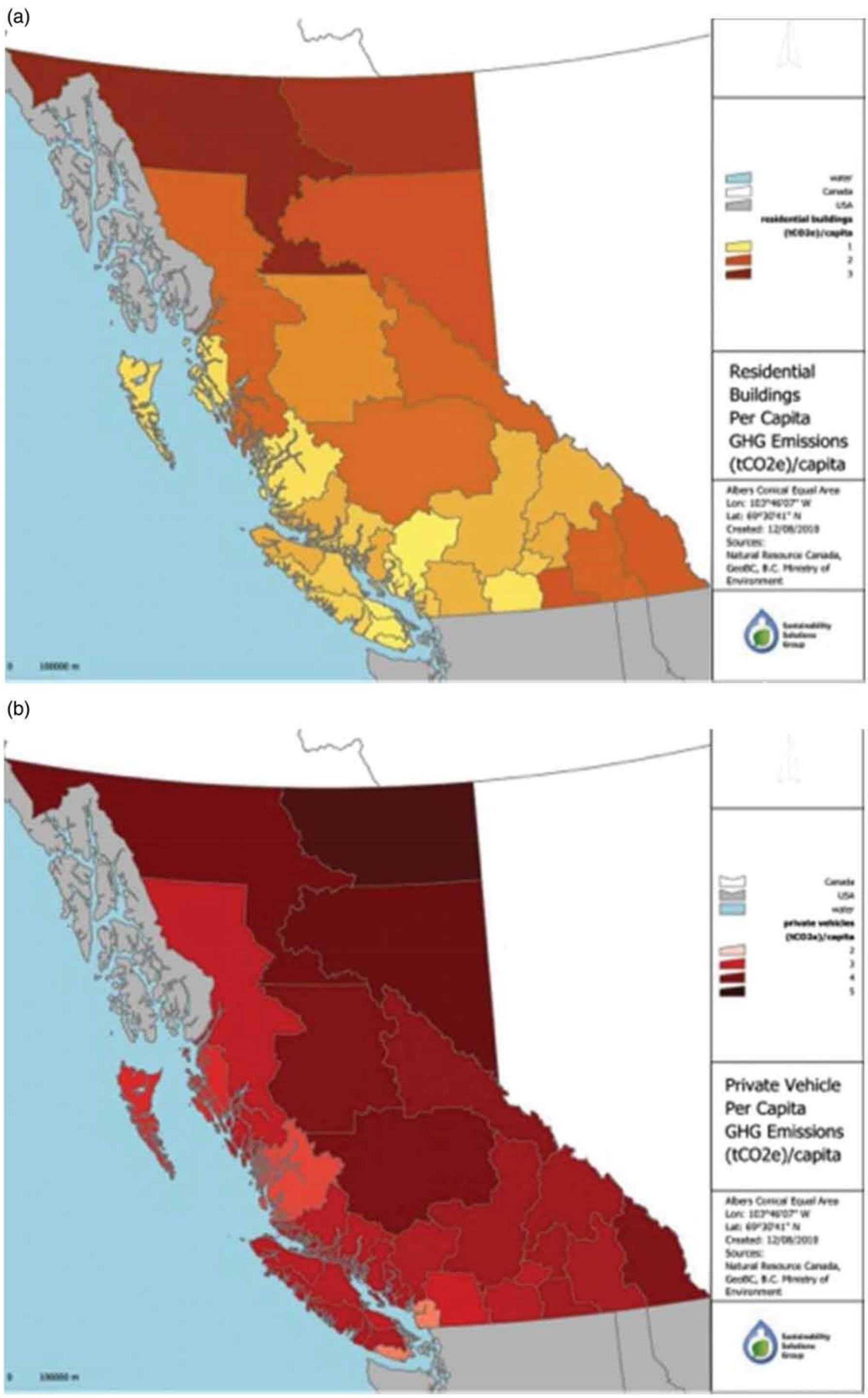

Figure 5. (a) GHG emissions from residential buildings by Regional District. *Per capita* GHG emissions from residential dwellings increase as one moves east and north and (b) GHG emissions from private vehicles by Regional District. Transportation GHG emissions show a stronger pattern of increase towards first rural regions and second northerly regions.

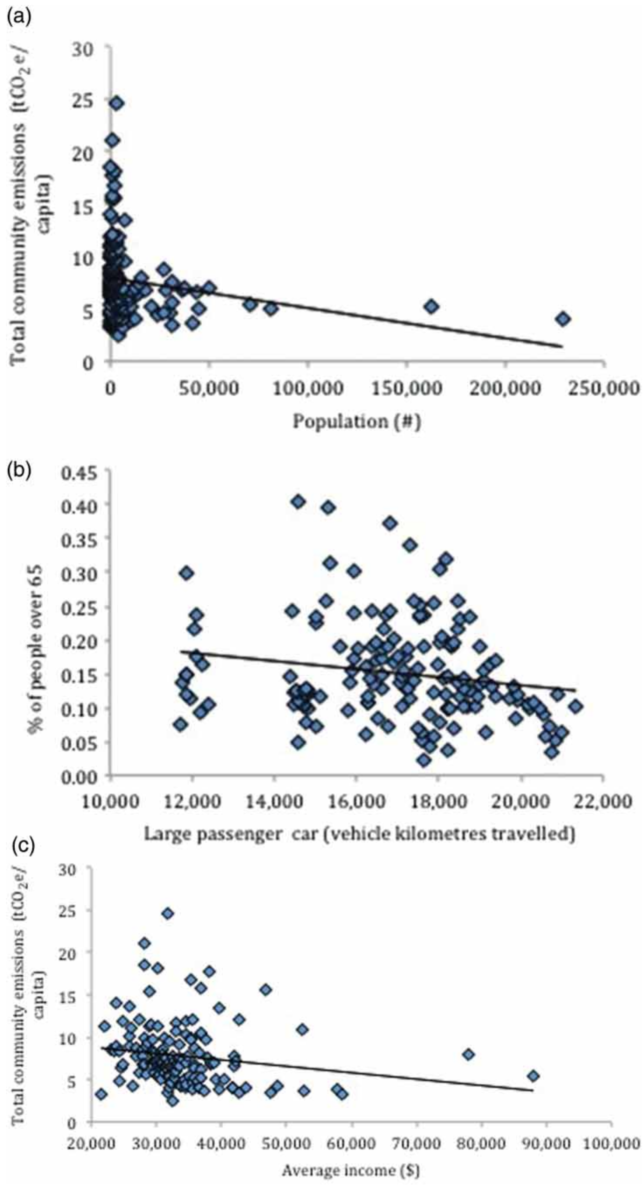

Figure 6. (a) Population and GHG emissions; (b) Age and VKT and (c) Income and GHG emissions. There is no notable correlation between community population sizes. No meaningful correlation was found between age and VKT or between income and GHG emissions.

expensive private transportation combined with public transportation may result in reduced vehicular travel. We considered the possibility that a higher percentage of people working at home might contribute to this result. However, since people working at home are not commuting this would not contribute to the mode distribution of commuting trips, rather the absolute number of trips by all modes would decrease. The Village of Slocan has half the density of Gibsons (5.1 people/ha) with commuting by vehicle at 21.5%. The main employer in Slocan, a mill, is located within walking distance of most of the houses.

Other communities with low levels of commuting by vehicle include Steward, Tofino, Whistler, Tahsis, Lytton, Valemount, Masset, New Denver, Nelson, Zeballos, and Smithers. Notably, many of these communities have highly developed downtown areas with a relatively compact spatial layout, indicating that proximity more than density could be a critical variable.

Despite having a very high density (62.9 people/ha), Vancouver's annual VKT for large vehicles is similar or even higher than many communities with much lower densities. This result may indicate that there is a relationship between people with large vehicles and high VKT irrespective of whether they live in a compact community or a rural setting. It may also be that large vehicles are used for work that is distributed over the landscape which is also independent of the spatial layout of the community. Abbotsford has high *per capita* VKT relative to its density (14.4 people/ha), perhaps because many people commute to other cities in the region that are further away, and if this is indeed the case it would be a primate candidate for a focused public transportation strategy.

5.3. Data quality and sources of error

This analysis was based on 2007 CEEI data, released in 2009. In 2010, the Government of BC released updated guidance documents, which included estimates for residential heating oil, propane, and wood use break out small and medium from large industrial buildings. The updates also include updated land-use change and new agricultural sectors and provide the first of a suite of supporting indicators. These would enhance the quality of data for future iterations of this analysis.

Potential sources of error are: data entry, data set limitations, and methodological limitations (for additional details on data source and quality, see Table 3). Data entry error is likely as over 13,202 data points that were compiled in a worksheet. The data were charted and any obvious anomalies were investigated and corrected. The data sets also give rise to methodological limitations. For example, national, provincial, and municipal parks were removed from municipal boundaries to calculate density; however, the presence of large water bodies (lakes or rivers) could reduce the density in a way that distorts the analysis. As another example, the VKT data set compiled by the Province of BC is based on actual mileage readings from the AirCare programme in Metro Vancouver. These mileage readings have been extrapolated to other communities in BC using a modelling process and may not fully reflect the actual VKT within particular communities (Pacific Analytics Inc. 2008). As the Government of BC improves its data over time, the

Table 3. Data source and quality.

Category	Data source and quality
Transportation	Vehicle models identified using insurance records but VKT for the Province is modelled based on the measurements from one urban region and is calibrated using a limited data-set of odometer readings completed when a vehicle changes ownership. Validation of the results not yet possible at the level of municipality
Buildings	Electricity and natural gas are obtained directly from the utilities. Heating oil, propane, and wood are estimates based on the number and type of dwellings in each jurisdiction. There are also issues with accurately assigning data to municipal boundaries
Solid waste	GHG emissions are modelled using assumptions for methane generation rate and methane generation potential

analysis can be repeated and improved. In terms of the methodological limitations of the analysis, we used a simple regression to test for correlations.

6. Pathways to a low-carbon future in BC municipalities

Our analyses indicate that municipalities in BC may have many lessons to share with one another regarding the pathways to a low-carbon future. However, comparisons must be undertaken with care, since municipalities differ from each other in multiple dimensions. For example, the analysis indicates that any municipality needs to consider the geographical location of its comparator communities; if they are further south, their GHG emissions will likely be lower. However, population, income, and geographical size do not have a significant influence. Proximity between dwellings and destinations, as opposed to density, may have an influence as well as accessibility and/or walkability. A given municipality should consider transportation patterns (transit, accessibility, and walkability) in its comparator communities carefully as this is a proxy for the overall community GHG emissions. Density may play a small role and is worth noting but does not appear to be a key driver.

The correlations (or lack thereof) described above suggest specific ways in which efforts to reduce emissions in one community might be instructive to another. Opportunities for sharing lessons learned might in fact be greater than previously assumed, given that very weak correlations exist between GHG emissions *per capita* and population size, as well as GHG emissions and income.

Since residential fuel mix correlates so strongly with GHG emissions but dwelling type does not, the path followed by the City of North Vancouver (a dense urban community with a population of approximately 48,000) with regard to district energy development might be of more use to a community such as Revelstoke (a low-density, relatively remote community of 8000 that is just beginning a transition towards renewable energy) than might otherwise be thought.

6.1. Implications for community climate change action and provincial policy

The relative unimportance of population, income, and geographical size may reveal the flaws in some arguments against the carbon tax or the barriers faced by municipalities as they explore GHG reductions, but these findings suggest that other factors are at play in determining emissions. First, we must look to the variables that *do* shape emissions and then explore the sociocultural, political, and technical roots of these variables.

Transportation has a greater impact on emissions than dwelling type, but density may impact fuel mix in ways not captured by the data above. For instance, in order to make district energy systems viable, commercial and residential buildings should cluster in corridors along which the district energy infrastructure is located. This need for density echoes other studies of the drivers of emissions in cities of global significance (Dodman 2009), but also requires a more nuanced look at the spatial patterns of development in cities. Rather than density, the more important determinant of transportation emissions may be land-use: the co-location of services, residences, and opportunities for work and play. Land-use is largely under the control of municipalities, giving all municipalities jurisdictional power over a major source of emissions.

This raises the "chicken and egg" challenge that the City of Surrey faces. Responsibility for transportation planning does not solely rest in the hands of the municipality. In the Lower Mainland of BC, for instance, Translink determines that allocation of mass and rapid transit for the region as a whole and province is largely responsible for funding this. Without the provision of rapid transit, municipalities face challenges in achieving density, but Translink does not allocate transit until density thresholds are met. This means that municipalities must creatively use other tools at their disposal to trigger density, such as bylaws, density incentives for developers, and land-use plans. A combination of these approaches, combined with social marketing, may prove to more effectively trigger emissions reductions at the household level (Dietz et al. 2009).

Since density is much less strongly correlated with GHG emissions than residential fuel mix, municipalities that face public backlash against density proposals may still pursue a low-carbon development pathway by tackling transportation emissions and residential fuel mix. Control over both the former and the latter, however, rests largely with the provincial government rather than municipal governments, by the way of provincial transportation funding and the BC Building Code. This reinforces the potential power of the land-use-based approach described above, while explicitly recognising the habits, values (cf. Slovic et al. 2007), and issues of identity (cf. Wynne 1992) that may form the roots of such a backlash in the first place.

Objections to the carbon tax have often focused on the unfair burden that it might place on rural and northern homeowners. Our data suggest that these claims may be valid (as emissions are generally higher in these areas), but the design of the carbon tax aims to offset these differences. For instance, the carbon tax funds income tax credits given to low-income families as well as northern and rural homeowners, compensating them in part for the added burden of colder weather and longer distances that must be travelled to locate services.

In sum, the analysis provided in this paper suggests that a low-carbon community in BC is one that has low GHG emissions from transportation. VKT per household is as low as is the percentage of commuting trips by car. Dwellings and destinations are likely in relatively close proximity and the community is likely dense, but it could have either a large or a small population. The community is likely in the south-west of the Province, but it could be located anywhere in the Province. Residential emissions, while less important than transportation, are also low, but the mix of dwelling types does not appear to matter – a high proportion of electricity for residential energy use is more important. The community could consist primarily of single-family residences or of a mix of all types of dwellings. Average income levels do not appear to matter and the community could be either wealthy or poor, as measured by an average income of the residents. The average age of the community also does not appear to matter. Factors that *are* very likely to matter, however, are not captured here, such as the cultural preferences of a population for density, perceptions of environmental risks, compelling examples of leadership that trigger broader uptake or sharing of experiments, and the extent to which GHG reduction strategies are designed and implemented through the legitimate participatory processes. These dimensions of community-scale innovation on climate change are the subject of ongoing research and are discussed elsewhere (Burch et al. 2014, Shaw et al. 2014).

7. Conclusions and future directions

This paper carries out a preliminary scan of GHG emissions data produced in the Canadian province of BC as part of the provincially mandated CEEI process. This is a new, and rapidly evolving, effort to gather robust data for all municipalities in the province over time, providing a foundation upon which targets and mitigation initiatives can be designed and implemented.

These results are important for BC municipalities because, by focusing on transportation and increasing density, any community can embark on a low-carbon pathway irrespective of its wealth and population size. Low-carbon communities can be created anywhere in BC and be of any size and of any position on the income-level spectrum. This finding is particularly important as it suggests that the potentially intransigent factors of income and location need not be barriers to achieving significant GHG reductions. The policy onus thus falls squarely on transportation planning, land-use, energy conservation, and fuel switching, from fossil fuels to renewables. The analysis also demonstrates that deep GHG emissions reductions are possible because some communities already have *per capita* GHG emissions reductions that represent an 80% reduction over other communities with higher *per capita* GHG emissions. It is much easier for a community to plot a path into the future when it can visit a living, breathing example of what it hopes to achieve, specifically related to public transit, accessibility, proximity, density, and residential energy consumption.

Though still under a process of refinement by the provincial government, the release of 2010 CEEI data in the spring of 2012 (the next iteration of the data presented here) has created the opportunity for the analysis of the data over time addressing questions such as: in which communities have GHG emissions increased and why and conversely and in which communities have GHG emissions decreased and why? Combined with the longitudinal analyses, it will also informative to examine the various collective and individual factors (such as awareness of climate change, collaborative modes of governance, and policy alignment between levels of government) that may trigger sustained transitions towards the low-carbon, resilient development pathways.

Many of the lessons learned here are transferrable to other communities and regions around the globe. In particular, these findings suggest that a move away from focusing on geography, income, and population is warranted in favour of a deeper analysis of the sociocultural and political drivers of land-use planning. This tension between laying the blame on exploding populations *vs.* a culture of consumption or governance mechanisms, for instance, is captured by Rosa and Dietz (2012) and suggests that a blend of production and consumption-based GHG inventory methodologies may provide greater insight into opportunities for mitigation. While population certainly influences absolute quantities of emissions in a community (cf. Angel et al. 1998), communities of varying sizes may have experiences with technological innovation, land-use planning, and public participation that are relevant for communities with very different population profiles. The sociocultural characteristics that do appear to shape GHG outcomes, however, are exceedingly variable, making parallels between nations and communities challenging to draw. Robust meta-analysis and cross-case comparisons may make this task more feasible, however, and serve to inform the next generation of community-based inventories and mitigation strategy development.

Notes

1. These data can be downloaded here: http://mc3.royalroads.ca/sites/default/files/webfiles/CURA_communityprofiles.xls.
2. For more information on these District Energy systems, see findings gathered by 'Meeting the Climate Change Challenge' (2011).
3. The number of kilometres travelled by each vehicle in a municipality can be ascertained using a variety of measures, including odometer readings, traffic counts, surveys, and transportation models.

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