Anthropogenic Drivers of Neighbourhood-Level Carbon Dioxide Emissions in Montreal

by

Mitchell Andrew Lavoie

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Department of Geography
McGill University
Montreal (Quebec) Canada

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ABSTRACT

The urban carbon cycle describes the relationship between urban form and carbon dioxide emissions from human activity in cities (Pataki *et al.* 2006). However, a mere handful of studies explore how the built environment affects carbon dioxide emissions both directly, through reduced carbon sequestration capacities, and indirectly, through population travel behaviour (Grimmond *et al.*,1987; Ewing *et al.*, 2008;). This thesis takes advantage of a unique opportunity to compare high-quality neighbourhood-level CO_2 data to travel behaviour along an urban-suburban-exurban gradient in Montreal. It interprets CO_2 observations collected in the scope of the Environmental Prediction in Canadian Cities Project (EPiCC) in light of urban travel trends computed from the Agence Métropolitaine de Transport's 2003 Origin-Destination Survey. Factor analysis is used to group census tracts sharing similar urban form and demographic composition such that urban, suburban and exurban travel behaviour can be compared to CO_2 concentrations and fluxes from these different neighbourhood types. Although mature suburban and exurban neighbourhoods were found to be effective daytime carbon sinks in the summer, their inhabitants use more carbon-intensive modes of transportation. As a result, urban neighbourhoods less capable of sequestering carbon measure higher levels of CO_2 despite showing greater use of public and active transport. These findings suggest that transportation policy reform targeting suburban and exurban travel behaviour may be a key step toward achieving the carbon-neutral city.

CHAPTER 1: INTRODUCTION

The industrial revolution of the 1700s is the oft-cited starting point of human drivers of climate change. Since then, cities continued to grow with heavy costs to the natural environments people depend on. Human activity has been linked to greater concentrations of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and a vast array of other greenhouse gases in the atmosphere (Ibid.). Fossil fuel combustion and cement production are responsible for 75% of the increase in atmospheric CO_2, considered the greatest contributor to global warming, since the industrial revolution (Ibid.). The automobile was, and continues to be, a key factor in climate change as it represents a direct link between individuals and fossil fuel emissions (Ewing *et al*. 2008). However, the unprecedented mobility that this technology permitted also affected the structure of cities as the dream of low-density, pastoral residential settings became possible. The result is an urban form designed for personal vehicles, which indirectly condones fossil fuel emissions, not least of which carbon dioxide. The complex relationship between vehicle use and the built environment is therefore vital to our understanding of the urban carbon cycle as a driver of climate change.

The challenge lies in mitigating these impacts while continuing to develop built environments on a global scale. While the body of knowledge on climate change continues to grow, so do the anthropogenic emissions it seeks to curb (Forster *et al.* 2007). Thus policy-makers must work closely with scientists to understand how human activities, particularly in urban environments, contribute to the greenhouse effect and how these impacts can be reduced. It seems, however, that interdisciplinary communication regarding this trend is lacking.

This research takes advantage of a unique opportunity to bridge urban atmospheric science and commuting characteristics of urban populations in the context of Montreal, Canada. It attempts to form a deeper understanding of how the built environment affects people's travel behaviour and how this interaction relates to urban, suburban and exurban atmospheric carbon dioxide fluxes and concentrations. This is made possible through the use of neighbourhood-level CO_2 data from the Environmental Prediction in Canadian Cities Project (EPiCC) in tandem with the Agence Métropolitaine de Transport's 2003 Origin-Destination Survey and 2006 Canadian Census data. More specifically, this research asks:

1. How do urban form and demographic characteristics interact to influence urban travel behaviour?
2. How does urban travel behaviour relate to measured neighbourhood-level CO_2 trends along an urban-exurban gradient?
3. How does the geography of travel behaviour and anthropogenic CO_2 emissions inform research and policy on the "ideal" carbon-neutral city?

While the EPiCC project employs highly skilled researchers and advanced equipment to generate atmospheric data, it struggles to understand the role of anthropogenic activities in urban environments. Interpreting neighbourhood-level CO_2 trends from the project alongside census, travel behaviour and spatial data could bridge a fundamental gap between the natural and social sciences of cities to inform policy.

It is hypothesized that urban neighbourhoods, namely those with high dwelling densities and located near the central business district, will exhibit commuting behaviours reflective of close proximity to activity centres and multiple mode choices. Suburban neighbourhoods, on the other hand, will likely demonstrate high vehicle ownership and, consequently, a high number of vehicle displacements. However, a more vegetated built environment is expected to discount the effects of these behaviours on CO_2 trends. Finally, exurban areas, farthest from the central city, may also exhibit high vehicle ownership and use, but it is expected that commuting patterns will be more localized and detached from the metropolitan urban system. The CO_2 trends measured at stationary sites along this urban-exurban gradient are expected to reflect larger anthropogenic contributions as urban density increases. The spatial distribution of carbon-intensive individual and household behaviours is expected to differ, however, as lower urban density is conducive to long commutes by car. Support for these hypotheses would indicate a need to approach the question of urban carbon with both empirical measurements and observations on population behaviour.

CHAPTER 2: A MULTIDISCIPLINARY PERSPECTIVE ON URBAN ANTHROPOGENIC CARBON

Literature on urban greenhouse gas emissions can be found in multiple disciplines, namely atmospheric science, urban planning, environmental management and transportation. Many governments and non-governmental organizations also publish documents pertaining to anthropogenic climate change and sustainable urban development. The interest in urban carbon is therefore far-reaching, and each discipline offers a different perspective on the sources, measurement and mitigation of anthropogenic emissions in cities. Few studies tackle anthropogenic greenhouse gas emissions from multiple perspectives, however. This disciplinary language barrier limits the depth of understanding of the urban carbon cycle.

While physical scientists measure emissions using advanced technologies, social scientists attempt to explain these emissions in terms of human activity. Each point of view brings new complexity to the urban carbon cycle, and the first step to gaining a better understanding of this human-driven process is to bridge this ideological gap. The following subsections outline the methods and findings of the main disciplinary streams related to anthropogenic climate change in cities. The atmospheric science, urban design and urban transportation literature is explored in an attempt to highlight key interdisciplinary links and disagreements on the topic of urban carbon.

2.1: The Greenhouse Effect and the Global Carbon Cycle

The earth is heated by incoming solar radiation and cooled by emitting infrared radiation into space (Kump, Kasting and Crane 1999). Atmospheric gases, known as greenhouse gases, regulate both of these processes by selectively absorbing or reflecting incoming and outgoing radiation (Ibid.). These gases may ‘trap’ outgoing infrared radiation while allowing solar radiation to penetrate Earth’s atmosphere (Ibid.). The result is an atmospheric heating known as the greenhouse effect. A common misconception treats the greenhouse effect as a negative process for the global environment, but Earth would not be habitable without it (Ibid.). The current concern with climate change lies in the excessive emission of greenhouse gases leading to increasingly severe weather conditions (Ibid.). Carbon dioxide (CO_2) is second only to water vapour as the greenhouse gas with the greatest concentration in the atmosphere (Ibid). Therefore, understanding how it is cycled through the earth system is an important step in grasping the concept of climate change.

The global carbon cycle consists of stores and exchanges between the atmosphere, hydrosphere, terrestrial biosphere, and lithosphere (Schimel *et al.* 2000). In the absence of human activity, this cycle is essentially balanced (Ibid.). However, measurements of atmospheric CO_2 since 1957 have captured anthropogenic inputs, mainly from fossil fuel combustion, to the atmosphere (Ibid.). Because the global reservoirs cycle carbon on different time scales, these inputs to the atmosphere are not balanced with equal outputs (Ibid.). Atmospheric CO_2 then accumulates, which exacerbates the greenhouse effect. Humans, therefore, have an important effect on global carbon cycle. This warrants special attention to urban environments, where anthropogenic activities are most concentrated. In response to this, some authors propose an urban carbon cycle that conceptualizes CO_2 emissions in terms of manmade environments and processes (For example, Pataki *et al.* 2009).

2.2: The Urban Carbon Cycle: Why do Cities Matter?

Urban environments are responsible for 80% of total global carbon dioxide emissions (Churkina 2008). Yet a mere handful of atmospheric science studies address the impact of cities and anthropogenic activities on the global carbon cycle. As world populations continue to urbanize, a holistic approach to identifying the direct and indirect influences of human activity on the carbon cycle at the urban scale becomes imperative. The dynamic interplay between people and the built environments they inhabit therefore needs deeper understanding in tandem with trends in urban carbon emissions.

Andrews (2008) proposes an inverted u-shaped curve for urban greenhouse gas emissions, which identifies trade-offs between the sink capacity of the surrounding environment and the consumptive behaviours of its inhabitants. While suburban areas with abundant green-space may naturally absorb carbon, the greater energy use associated with larger homes, residential landscaping and greater travel distances in these areas increases anthropogenic inputs to the carbon cycle (Ibid.; Jo and McPherson 1995). Conversely, high-density urban residential areas typically have far lower natural carbon sinking capacity, but smaller dwelling sizes, shorter travel distances and greater access to public transit contribute to less carbon-intensive human activity (Ibid.). The author concludes that building at very high densities to maximize the viability of public transit is the best mitigation strategy for vehicular greenhouse gas emissions in cities (Ibid.). Findings from Stone (2007) point to a similar imperative of urban densification as opposed to suburban infill development to reduce anthropogenic emissions. A modeled 10% increase in urban residential density produced a 3.5% decrease in vehicle miles travelled, which translated into a 5.1% decrease in CO_2 concentrations compared to the business-as-usual scenario (Ibid.).

Pataki *et al.* (2006) identifies an increase in fossil fuel emissions as the most prominent impact of population growth on the urban carbon cycle, with the residential and transportation sectors accounting for 40% of total U.S. fossil fuel emissions in 2001. As urban growth accounts for most of this population accretion, understanding the carbon cycle at the scale of the city is crucial (Ibid.). Ewing *et al.* (2008) further emphasize this need in stating that reducing CO_2

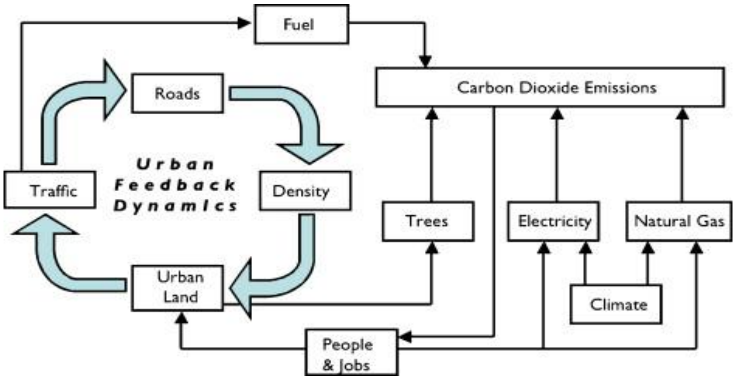
emissions by at least 60% below 1990 levels by 2050, as prescribed by the Intergovernmental Panel on Climate Change, cannot be achieved solely by improvements in vehicle technology. Their work demonstrates that studying the interplay between urban form and commuting behaviour makes a vital contribution to our understanding of the role of cities in the global carbon cycle.

With increased awareness of urban carbon cycling, a new body of research emerged aiming to identify carbon sources and sinks from built environments. For instance, Grimmond *et al.* (1987) used the eddy covariance technique to measure surface-atmosphere CO_2 exchange in Chicago, separating anthropogenic sources from biophysical sources and sinks. The author concludes that CO_2 concentrations at a height of 27 metres reach a maximum in the morning due to rush hour vehicle traffic, nocturnal vegetative respiration and shallow night-time atmospheric mixing layers (Ibid.). She also claims that urban environments are a net carbon source due to the persistent influence of mobile and built emitters and their capacity to outweigh photosynthesis, even in densely vegetated and well-irrigated suburban neighbourhoods (Ibid.). Coutts *et al.* (2007) further emphasizes the secondary influence of urban vegetation as carbon sinks on the city scale in suggesting that traffic volumes are the largest contributor to suburban CO_2 fluxes. The implications of these findings for understanding the urban carbon cycle are numerous. Although Grimmond *et al.* (1987) quantifies CO_2 fluxes for an urban area and gives some indication of anthropogenic sources, they evade explaining the relationship between urban form and human consumption behaviour that contributes to these fluxes. By focusing research on a single measurement site in a city, their research glosses over the role of urban dynamics, namely the physical and behavioural differences between urban, suburban and exurban neighbourhoods that may help explain intra-urban disparities in CO_2 emissions.

Pataki *et al*. (2007), on the other hand, recognizes the importance of the urban-exurban gradient in cities by plotting the magnitude of the urban CO_2 dome over the Salt Lake Valley in Utah. Using isotopic mass balance, his research quantifies diurnal and annual CO_2 concentrations originating from different biogenic and anthropogenic sources at an urban, suburban and exurban site in the metropolitan area between 2004 and 2006 (Ibid.). The highest concentrations occurred during wintertime temperature inversions in the central business district, purportedly due to space heating with natural gas, while photosynthesis likely explains lower summertime concentrations (Ibid.). However, an earlier study by Idso, Idso and Balling (2001) measuring the CO_2 dome over Phoenix, revealed pronounced differences in weekday versus weekend CO_2 concentrations measured in the central city of Phoenix, suggesting vehicular traffic brought in by weekday commercial and business activity is to blame for higher weekday concentrations (Ibid.). The relative contributions of different human activities to the diurnal and annual urban carbon cycle and the influence of the built environment on these contributions thus remain unclear.

Pataki *et al.* (2006) attempts to address this problem by treating urban areas as ecosystems comprising positive and negative environmental feedbacks from built and natural environments and human behaviour. Countering past emphasis on atmospheric science research in understanding urban greenhouse gas emissions, he professes the need to adopt a multidisciplinary approach that includes engineers, urban planners, social scientists and physical scientists in this body of knowledge (Ibid.). The contributory variables he identifies reflect this imperative: population and dwelling densities, rate of population growth, affluence, technological innovation, building characteristics, the transport network, vegetation and soil characteristics, and land use change (Ibid.). In a subsequent study, the author uses an ecosystem approach to link the physical and socioeconomic determinants of urban CO_2 emissions, postulating an interactive relationship between fossil fuel combustion and the nature of the built environment (Pataki *et al.* 2009). His research suggests that travel behaviour indirectly influences CO_2 emissions via an urban feedback loop of development density, land use, the road network and vehicle traffic, while biogenic factors have an impact both directly, through climatic and biological processes, and indirectly, through people's energy consumption in response to environmental conditions (Ibid.; see Figure 2.1). The prominence of the transportation sector in this model reflects its contribution to the urban carbon cycle. Furthermore, while transport-related nitrous oxide and volatile organic compound emissions are on a decreasing trend in the United States, carbon dioxide emissions from this sector continue to rise (Ewing *et al.* 2008). In Canada, the transport sector experienced a substantial increase in total greenhouse gas emissions from 1990 to 2006 (Environment Canada 2008).

Figure 2.1: A systems dynamics diagram of the interaction between urban sector activity, built form and CO_2 emissions (Pataki *et al.* 2009)



Although this diagram effectively depicts the agents of the urban carbon cycle, it implies a unidirectional relationship between human activity and urban form, namely choices of residential location and subsequent commuting patterns *resulting* in a built environment feedback loop. Many authors contend, however, that this interaction is necessarily multidirectional given market constraints on housing choice and individual circumstances compelling people to live in certain areas and to travel using available modes (Chatman 2009; Ewing *et al.* 2008;). Thus surveying the literature on the behavioural inputs to and outcomes of urban form will lead to a greater understanding of the human impact on the urban carbon cycle.

2.3: Urban form and Greenhouse Gas Emissions

Marquez and Smith (1999) propose a methodology for studying the effects of urban form on greenhouse gas emissions that distinguishes mobile, land-use, point-source and biogenic emitters. Growth scenarios and the gravity model of urban transportation are then used to model the emissions resulting from different urban development pathways (Ibid.). Although the compact development scenario was deemed least conducive to pollutant emissions, local weather patterns at the hypothetical site brought in air pollution from elsewhere in the city (Ibid.). This instance reveals the complicating factor of meteorological patterns in studies of anthropogenic emissions, particularly in the case of mobile emitters such as personal vehicles.

The rise in urban greenhouse gases emissions is often blamed on the increased vehicle dependence associated with urban sprawl, but several authors look beyond density to identify urban form characteristics conducive to greenhouse gas emissions (Andrews 2008). For instance, Reckien *et al.* (2007) contends that increasing building densities does not effectively reduce the impact of traffic infrastructure on urban CO_2 emissions. Rather, he argues that traffic area, or the amount of space allocated to vehicle circulation, must be reduced to constrain mobile carbon emissions in cities (Ibid.). Younger *et al.* (2008) also points to road construction and as a primary driver of increased vehicle traffic, which supports a supply-driven, environmentally deterministic view of anthropogenic carbon dioxide emissions in cities. New Urbanism strives to increase residential density and promote mixed land use to reduce vehicle dependence (Handy 1992). The compact built form suggested by this planning principle may have a more complex relationship to anthropogenic CO_2 emissions, however (Ewing *et al.* 2008). While modifying the built environment may influence human behaviour in the long term, the short-term outcomes of such a large investment are less evident (Ibid.).

Although these studies reflect the importance of the physical structure of cities in quantifying urban greenhouse gas emissions, they ignore the role of human agency in constructing and responding to the built environment. They also propose long-term, expensive interventions that focus on supply considerations (Ewing *et al.* 2008). Understanding how commuting behaviours arise may offer more short-term avenues for mitigation that employ households and individuals as agents in the urban carbon cycle.

2.4: Urban Form and Travel Behaviour

A 2006 report revealed that the transportation sector accounted for 49% of total greenhouse gas emissions in Montreal, 49% of which was attributed to personal vehicles (Logé 2006). Thus approximately 25% of Montreal's urban greenhouse gas emissions are due to commuting. This raises important questions about the link between these behaviours and the built environment, which has been explored extensively in transportation and urban planning literature. However, there is contention over the causality of these factors, reflecting the debate between proponents of environmental determinism on one side and self-selection on the other.

Many authors identify strong correlations between built environment characteristics and travel behaviour. Holtzclaw *et al.* (2002), for instance, determined that commercial density, transit accessibility, dwelling density and pedestrian infrastructure all covary in explaining vehicle use. However, a doubling of dwelling density alone was linked to a 30% decrease in vehicle use (Ibid.). Variations in behaviour among personal vehicle users have also been linked to urban form. For instance, Brownstone (2009) provides evidence that an increase in dwelling density leads to a decrease in vehicle distance travelled. However, this is countered by a greater propensity to 'trip-chain' in suburban environments, namely travelling to multiple destinations in one displacement (Stone 2007). This type of displacement is considered less energy-intensive than multiple separate trips, as the vehicle's engine is already warm for each subsequent trip component (Ibid.). Thus, there is evidence of a deterministic relationship between urban form and travel behaviour, although the carbon intensity of different behaviours complicates analysis of the role of the built environment in inducing mobile emissions.

Frank *et al.* (2000), on the other hand, explore land use as a determinant of travel behaviour through the variables of proximity, namely the linear distance between trip origins and destinations, and connectivity, the directness of transport routes between these points. He concludes that connectivity is the strongest predictor of trip frequency and travel demand among built form characteristics (Ibid.). However, he recognizes the influence of human agency in suggesting that individual attitudes affect choices of residential location and, subsequently, travel behaviour (Ibid.). Haas *et al.* (2008) also challenges the mutual exclusivity of environmental determinism and residential self-selection in a study of transportation costs and neighbourhood and household characteristics. Land use, employment density and transit supply are identified as key variables in travel behaviour modelling, but habituation and preferences are complicating factors (Ibid.). This is captured in Haas *et al.*'s (2008) observation that "mode choice may be based on preference, rather than convenience or cost, and miles travelled may be greater if households choose shops and services farther from their homes, even if the data show there are several closer"(Ibid.,64).

This relates to the theories of induced traffic and induced development, which suggest that individual preferences and behaviours influence the physical design of cities (Ewing *et al.* 2008). For instance, a cultural movement toward suburbanization may necessitate highway construction, which complements the reverse phenomenon of environmental determinism (Ibid.). Similarly, the location and physical design of a neighbourhood may necessitate personal vehicle use or offer a mode choice, but the decision to drive may be completely independent from these factors (Handy *et al.* 2005b). Thus the built form of cities may condone or inhibit driving, but individual preferences of residential location and service use cannot be disregarded.

Furthermore, neighbourhood factors such as safety, school quality and affordability may have greater influence in the residential selection process than available transportation modes (Ibid.). Alternatively, household travel survey analysis has shown that a high proportion of people choose their neighbourhood based on their pre-existing travel mode preferences, suggesting residential self-selection may be governed, in part, by supply of travel infrastructure (Chatman 2009). These confounding factors put the causal power of urban form on travel characteristics into question. As Handy *et al.* (2005) note, only the first criterion of causality, namely the statistical association of cause and effect, is met in this case. There is no consensus on the direction or mechanism of the relationship between urban form and travel behaviour, which complicates policy implementation (Ibid.).

2.5: Demographics and Carbon-Intensive Behaviour

The demographic underpinnings of urban transportation behaviour are well documented, but the relationship between the social characteristics of a neighbourhood and anthropogenic carbon dioxide emissions is less evident. The urban transportation literature identifies strong demographic correlates of particular travel characteristics, but seldom interprets these relationships as components of the urban carbon cycle. A small number of studies simultaneously explore the social makeup of a neighbourhood, the associated travel decisions and the resulting carbon dioxide emissions.

Frank (2000) indicates that household size is a strong determinant of trip generation and, consequently, household vehicle emissions. However, Stokes *et al.* (1994) shows that the number of adults is a stronger indicator of household CO_2 production, as it represents the population more likely to hold a driver's license and commute to work. This specification targets work-related displacements but overlooks the potentially significant impact of urban travel for non-work purposes, namely for shopping, school and leisure (Rajamani *et al*. 2003). The number of children per household then becomes a variable of interest in trip generation, mode choice and personal vehicle size (Ibid). While a greater number of adults is linked to higher driver's license holding and decreased household propensity to walk, a greater number of children is linked to increased rideshare due to mobility dependence (Ibid.). This demonstrates that carbon-intensive behaviour is not only a question of household size, but also of household composition.

Somewhat less explored is the link between socioeconomic status, ethnicity and household CO_2 production. Conventional wisdom says that wealth is synonymous with suburban environments and high vehicle ownership in North American cities. From an economic perspective, higher housing costs make larger dwelling units less affordable, while lower transport costs liberate more income for larger housing (Ewing and Rong, 2008). The latter scenario is typical of suburban environments, where dwelling units tend to be larger and vehicle ownership higher (Ibid.). Both of these characteristics are linked to higher household CO_2 emissions, but may not be a consequence of higher income. The recent trend of gentrification, namely the re-population of decaying urban neighbourhoods by wealthy professionals, is evidence of this (Ley and Frost 2006). However, the difference in population size between suburbanites and gentrifiers may explain why many authors identify a strong relationship between income and carbon-intensive behaviours such as trip generation (Ewing and Rong 2008; Stone 2007). Higher income may also be a good indicator of increased mobility and, consequently, vehicle ownership, notwithstanding dwelling location or size (Reckien *et al.* 2007). Individual demographic characteristics have also been studied to a limited extent for potential effects on commuting behaviour. For instance, Rajamani *et al*. (2003) found that a greater population of non-Caucasians was linked to a higher proportion of non-work trips made by walking in Portland, Oregon. Stone (2007) also indicates that employment rate can be used to identify neighbourhoods with similar commuting characteristics.

2.6: Linking Perspectives on Urban Carbon

Very few studies encompass both the physical science and social implications of the urban carbon cycle. Yet demographic characteristics and urban form at the neighbourhood level have been shown to affect human behaviours linked to higher CO_2 levels in the urban atmospheric boundary layer. Low-density urban form has been linked to both greater carbon sinking capacity and higher transportation energy use. Particular demographic characteristics have also been associated with increased vehicle displacements. Given this bi-directional relationship, more research is needed to understand how urban form and human behaviour fit into the urban carbon cycle.

CHAPTER 3: DATA AND METHODS

Most travel behaviour studies control for socio-demographics and treat only urban form characteristics as independent variables. However, it is unclear how the social makeup of neighbourhoods relates to consumption behaviours and subsequent carbon dioxide emissions in cities. The current study attempts to identify a ‘culture of carbon’ by treating social and built characteristics as equivalent potential drivers of commuting behaviour. This involved finding census tracts that have demographic and urban form characteristics similar to three CO_2 measurement sites in Montreal, installed for the EPiCC project. A principal components factor analysis model was deemed the most appropriate method for achieving this goal.

Stone (2007) suggests that demographic, socioeconomic and urban form characteristics can be used to identify clusters of neighbourhoods with similar commuting characteristics. They employ this method alongside the USEPA Mobile 6 vehicle emissions framework to generate a model linking urban form to air quality (Ibid.). Although that study’s input variables demonstrate a multidisciplinary approach, they are used for forecasting and are only partly complemented with actual data (Ibid.). The current research employs a similar three-component approach linking urban form and demographics to travel behaviour and anthropogenic emissions, but attempts to do so through secondary data collection and factor analysis.

3.1: Database Building and Context for Analysis

This section describes the four main sources of data used for analysis, namely CO_2 data from the Environmental Prediction in Canadian Cities (EPiCC) Project, demographic and housing data from the 2006 Canadian Census, spatial data from DMTI Spatial and the 2006 Canadian Census, and population displacement characteristics from the 2003 AMT Origin-

Destination Survey. It also explains how data were manipulated and stored in preparation for analysis.

3.1.1: The Environmental Prediction in Canadian Cities Project

The impetus for this research came from the Environmental Prediction in Canadian Cities Project (EPiCC), a collaborative undertaking involving four Canadian Universities, Météo France and Environment Canada (EPiCC 2008). It evolved from the observation that 80% of Canadians live in urban settings where the nature of the built environment and the consumptive behaviours of the population significantly influence atmospheric conditions (Ibid.). A team of academics, technicians and government researchers employ observation, remote sensing and modelling in two climatically different cities, Montreal and Vancouver, with the goal of creating a modelling system to improve meteorological prediction in all Canadian cities (Ibid.). The Montreal team collected surface energy balance data constantly between Fall 2007 and Fall 2009 at three observation towers located in the greater Montreal area (Ibid.). The urban tower is located in the residential Rosemont borough, the suburban tower in the Roxboro-Pierrefonds borough, and the exurban tower in Coteau-du-Lac, to the west of the Island of Montreal (Figure 3.1).

The urban Rosemont neighbourhood is characterized by attached, three-storey triplex housing with flat roofs arranged in a grid street pattern and served by alleyways. Many surrounding residential streets have mature deciduous tree canopies in the summer and each triplex unit typically has a small front and back yard. Several streets also have mixed land uses shared between residential and commercial occupancy. The neighbourhood is served by multiple public transit bus lines with frequent service that connect to the metro system (Agence Métropolitaine de Transport 2010). The observation tower itself was erected in the back yard of a triplex between the building and an alleyway. Construction of new housing and commercial spaces in the immediate environs is a known limitation to data quality at this site.

Figure 3.1: Location of the EPiCC Observation Sites

Montreal Metropolitan Region

Exurban Site (Coteau-du-Lac)

Suburban Site (Roxboro-Pierrefonds)

Urban Site* (Rosemont)

*Photo captured in fall
Source: Google Maps (2010)

The suburban Roxboro-Pierrefonds neighbourhood consists mainly of two-story and split-level single detached dwellings with pitched, shingled roofs. Lots typically have driveways and large front and back yards with abundant trees, shrubs and grass. Most residential subdivisions in the area have a curved, meandering street pattern with frequent cul-de-sacs. Large commercial spaces are concentrated along nearby des Sources Boulevard, segregated from residential land uses. A commuter train station to the north of the neighbourhood provides fairly rapid access to the central business district and some bus lines connect to local points of interest (Agence Métropolitaine de Transport 2010). The suburban EPiCC tower was erected in a large residential back yard relatively unobstructed by buildings or vegetation.

The exurban municipality of Coteau-du-Lac is dominated by agricultural land use. The tower was erected in a cornfield, distant from buildings, to provide a comparative baseline unaffected by anthropogenic activities. Cycles of crop growth are said to influence observations, however. Thus while the urban and suburban sites capture anthropogenic drivers of radiative heat flux and atmospheric composition, measurements at the exurban site are solely influenced by the biogenic processes of photosynthesis, respiration and soil flux from tilling (O. Bergeron, pers. comm.).

Under clear meteorological conditions, observations were collected at a height of 25 metres at the urban and suburban sites, while risk of lightning or other potentially damaging weather warranted a retraction of the towers to a height of 8 metres. Exurban site observations were taken one metre above ground level as a reference. The 25-metre measurement point represents neighbourhood-level atmospheric conditions, thus captures anthropogenic inputs to the surface energy balance (O. Bergeron, pers. comm.). The 8-metre position, however, sits in the roughness sub-layer and captures mainly localized conditions (Ibid). It is important to note that winds in the Montreal region predominate from the west, meaning points east of the industrial parks in Saint-Laurent the central business district likely experience higher air pollution levels. Thus the Urban

EPiCC tower likely captures a larger baseline level of air pollution, which must be considered when interpreting observations.

Although the surface energy balance is the primary interest of the EPiCC project, each tower was equipped with an open-path infrared gas analyzer, which measured CO_2 concentrations and fluxes. The instrument collected observations at a frequency of 20 Hz, which were then used to calculate half-hourly means in post-processing (Ibid.). Its open-path nature made it vulnerable to rain and frost events, however, which somewhat compromised data availability (Ibid.). The sheer volume of observations collected nonetheless permits the plotting of high quality seasonal and diurnal CO_2 trend-lines.

This thesis uses these data, arranged on an urban-exurban gradient, to better understand how humans contribute to ambient concentrations of CO_2 in cities. Due to data protection policies, Bergeron (pers. comm.) generated relative CO_2 concentrations and fluxes using the amplitude and maximum of measurements at the exurban site, respectively, for use in this research. He calculates ten-day means from 01 October 2008 to 30 September 2009 to depict seasonal trends and ensemble averages from 15 January to 15 March 2009, and from 15 May to 15 September 2009 to depict summer and winter diurnal trends at each site (Ibid.). Although these numbers are not absolute, they preserve the relative trends observed at the urban, suburban and exurban sites.

3.1.2: Census Data

For the purposes of this research, the EPiCC sites are treated as emblematic of urban, suburban and exurban neighbourhoods in Montreal. To draw hypotheses about the relationship between CO_2 trends and human behaviour for different types of urban form, neighbourhoods must be selected as geographic and demographic peers of the three EPiCC sites. Canadian Census data from 2006 was used to paint a more comprehensive picture of the social and built characteristics of neighbourhoods in Montreal. Several variables either proposed in the literature or currently unexplored were constructed from these sources to select neighbourhoods that may house individuals with similar carbon-intensive behaviour.

The 2006 Canadian Census contains a wealth of datasets with individual, household and property characteristics. In Census Metropolitan Areas (CMAs), such as Montreal, this information is appended to spatial units called census tracts (Statistics Canada 2010). These areas are considered demographically stable through time and typically contain between 2,500 and 8,000 people (Ibid.). Thus they are a convenient proxy for neighbourhoods and allow for statistical and geographic analysis. This relative numeric uniformity, however, means that population density governs the size of census tracts. Therefore, in exurban areas with sparse population, census tracts are large and may not suitably represent neighbourhoods.

Census data for the Montreal CMA was accessed via University of Toronto's CHASS Canadian Census Analyzer. Variables selected include: Average number of children per household, household size (Frank 2000), unemployment rate, median after-tax family income (Frank 2000), mother tongue, Canadian citizenship and structural types of dwellings. The latter was used to calculate a dwelling density indicator, namely the percentage of dwellings classified as duplex, row-house, apartment with fewer than five stories, or apartment with greater than five stories in each census tract. These four categories represent high-density dwellings typical of urban neighbourhoods, thus higher percentages are associated with a more dense urban form.

3.1.3: Geospatial Data

Once compiled, the above-mentioned census dataset was stored in ESRI's ArcMap geographic information systems software using census tract boundary files for the Montreal CMA (provided by the McGill Geographic Information Center (GIC)). This vector shapefile allows for spatial analysis of census data and greater understanding of the spatial context of the census tracts themselves. One variable calculated from the boundary files is the linear distance ("as the crow flies") between census tract centroids and that of the census tract containing the largest portion of the central business district.

The McGill GIC also provided DMTI Spatial land use data from 2008. The vector shapefile identifies land cover types in the entire Montreal CMA according to six categories (excluding water). Because census tracts vary in size and shape, any relative measure of land use at the census tract level would inaccurately depict neighbourhood-level conditions. To surmount this constraint, two indicators of land use mix within census tracts relevant to carbon emissions and travel behaviour were calculated: proportion of commercial land use to residential land use and proportion of green-space land use to residential land use. Rajamani *et al.* (2003) used the latter was used in a travel behaviour study. First, each land use type was isolated using ArcMap's "Select by attributes" and "Dissolve" functions. Second, the surface area occupied by each land use per census tract was calculated using the "Polygon in Polygon Analysis" application in the Hawth's Tools extension. Finally, the areas covered by commercial and green-space land use were divided by residential land use area. The main problem with these measures is that they do not account for building densities. Thus it may seem, for instance, that suburban areas are well served by large swaths of commercial space when a large amount of that land is covered by parking lots.

3.1.4: The Montreal Metropolitan Region Origin-Destination Survey

An origin-destination (O-D) survey is the primary source of information about peoples' displacements in cities (AMT, 2009). It collects demographic characteristics, the locations of households, trip origins and destinations, as well as various characteristics about those trips at the level of individual displacements (Ibid.).

Montreal's *Enquête Origine-Destination* has been executed every five years since 1970 through a partnership including the Agence Métropolitaine de Transport (AMT), the umbrella organization overlooking transportation in the Greater Montreal Area—various public transportation commissions, notably the Société de Transport de Montreal, the Société de Transport de Laval and the Réseau de Transport de Longueuil—and the Ministère des Transports du Quebec (MTQ), the provincial transportation ministry (Ibid.). Although the most recent O-D survey was disseminated in 2008, data release was too late given the time frame of this study. Thus the 2003 O-D survey was used for analysis.

The 2003 O-D survey was performed between September 2003 and February 2004 in the Montreal Census Metropolitan Area, comprising 88 municipalities and 3,613,000 people (Ibid.). It collected information from 59,965 households, or nearly 5% of Montreal-area households, and had 137,042 respondents effecting 300,794 displacements (Ibid.). Each displacement and household was assigned a unique identification number, thus permitting analysis at both levels. Values are listed according to a numeric coding system to ease analysis of categorical data, and geographic coordinates and census tracts are provided for use in geographic information systems.

The raw data was provided by the McGill School of Urban Planning in abbreviated form due to information dissemination restrictions, although no displacements were omitted. The dataset was uploaded to ESRI's ArcMap GIS software and displayed as x-y coordinate points of households. Microsoft Excel was used to compute statistics beginning from the tabular form of the survey.

3.2: Factor Analysis and Neighbourhood Group Selection

A factor analysis of spatial and census data was used to generate groups of neighbourhoods with similar demographic characteristics and urban form. The goal was to create three peer groups of census tracts to represent the urban, suburban and exurban built environments surrounding the three EPiCC sites, such that general travel patterns tied to these different types of urban form could be inferred. Aggregating information into such large spatially and socially heterogeneous groups greatly simplifies descriptive analysis of CO_2 trends in relation to anthropogenic activities.

3.2.1: Factor Analysis in a Nutshell

Factor analysis is a multivariate statistical tool intended to reveal relationships and clusters among standardized variables, thus eliminating redundancies and streamlining a dataset (Agresti and Finlay, 1997). It produces a smaller, researcher-defined number of uncorrelated, “artificial” variables called factors that are linearly related to the original input variables (Ibid.). Factors are calculated such that each pair of original variables has a correlation of zero in the output factor dataset (Ibid.). The latter consists of Pearson correlations, known as loadings, of a factor with the values of each original variable (Ibid.).

There are various ways of verifying the fit of a factor analysis model. For instance, the proportion of variability explained by the factors can be determined by calculating communalities, namely the sum of squared loadings per variable (Ibid). A higher communality signifies that the set of factors has greater explanatory power over the input variables (Ibid.).

Interpretation of factors is simplified if each input variable highly correlates with only one or two factors (Ibid.). A factor rotation is an operation that attempts to bring most factor loadings close to zero such that each variable is explained primarily by few factors (Ibid.). The researcher can then use the high factor loadings to identify groups of input variables explained by a single factor (Ibid). There are many rotation methods available that should be chosen based on whether the factors are expected to be independent of each other.

Although factor analysis is convenient for data reduction and clustering, there are considerable assumptions and limitations. The creation of "artificial" factors means that subsequent analysis is based on variables that do not exist, but merely represent a group of input variables (Ibid.). Thus the usefulness of factor analysis is determined by how interpretable the factors are, namely how evident their explanatory power is and how they group input variables (Ibid.). Furthermore, it assumes input variables are normally distributed and pairs of variables are linearly related to each other (Ibid). Consequently, the researcher must learn about variable distributions before performing a factor analysis and use caution when interpreting output.

3.2.2: Using Factor Analysis to Identify Neighbourhood Peers

The main challenges of identifying census tracts with similar social and built form characteristics are determining what 'similar' means and how to measure it. Factor analysis is well suited to these goals when coupled with knowledge of the data and its geographic context. The desired output was three groups of census tracts (one "urban", one "suburban" and one "exurban"), each containing a census tract with an EPiCC tower, that exhibit relative within-group homogeneity among built form and social characteristics. The ten variables defined in previous sections were first standardized, as the factor analysis assumes, then run through the model using the "Principal Component Analysis" function in SPSS. The number of factors was set to three to increase the probability of generating strong variable groupings while keeping the output dataset small. The factors were then rotated using the “Equamax” method, an orthogonal rotation best used when factors are expected to be independent of each other. The program generates a Pearson correlation matrix and a communalities table of the input variables, the percent of variance explained by the factors, the actual factor values and the rotated factor values. Thus three new “artificial” variables that represent the original dataset are created, which simplifies the process of selecting “similar” census tracts.

The mean and standard deviation for each factor are one due to the prior assumption of a normal distribution. The factor values for each census tract containing an EPiCC tower were identified as the baselines on which similarity would be established. Using sorting tools and trial and error, it was decided that census tracts with factor values within one-quarter of a standard deviation, or ±0.25, from the tower census tract values are “similar”. This process was repeated three times, ensuring census tracts fell within this range for each factor. The three resultant groups contained between 10 and 14 census tracts, which were then subject to ground-truthing and data verification to test relative within-group homogeneity. Mean group values for all input variables were computed and tabulated to easily assess between-group variation.

If the factor analysis and filtering process yielded significant outliers among groups for certain variables, a manual selection was performed. This involved making observations based on proximity to the central business district, dwelling density and intuitive knowledge of the Montreal urban fabric. Although more subjective, this supplemental method tests the strength of factor analysis in identifying neighbourhoods with similar land use and social characteristics.

3.3: Travel Behaviour Analysis

The census tract groups chosen for analysis, as described in the previous section, were selected in ArcMap using the “select by attributes” function in the census tract layer. New layers were then created for each group. The same method was applied to the O-D survey layer, yielding points layers containing only the origins and destinations of people inhabiting the selected census tracts. Thus each census tract grouping was given its own O-D data table, permitting analysis at the group level.

The O-D variables used for analysis include: Number of vehicles per household (Frank 2000), driver’s license holder (yes/no), displacement motives, displacement modes (up to three) and network distance for car trips to work. The latter was provided by the McGill School of Urban Planning as output from ArcMap’s Network Analyst extension, which calculates the shortest path, given defined costs, along the road network between an origin and destination point. Aggregation of displacements to the level of households (required for certain desired statistics) was performed using Microsoft Excel’s “remove duplicates” and “Pivot-Table” functions in the household I.D. field. Given the numerical categorization of data, commuting behaviour statistics were computed simply by sorting fields, counting values and calculating means.

CHAPTER 4: URBAN FORM AND DEMOGRAPHIC CHARACTERISTICS OF NEIGHBOURHOOD PEERS

Given the empirical nature of the neighbourhood selection process, it is vital to grasp the meaning of the factor analysis output and the characteristics of the groups derived from it. This chapter discusses how various demographic and urban form variables relate. It presents and interprets the results of the factor analysis as a contextual foundation for understanding commuting behaviour in relation to neighbourhood-level CO_2 trends.

4.1: Relationships among Input Variables

A two-tailed Pearson correlation matrix reveals that many of the selected demographic and spatial variables strongly correlate at 5% and 1% significance levels for the 860 census tracts used in the factor analysis (Appendix A). The strength of factor analysis is that significantly correlated variables need not be omitted beforehand because the operation groups variables according to these relationships (Agresti and Finlay 1997). However correlations should be considered when analyzing commuting characteristics, as they offer a more comprehensive understanding of how and why these behaviours arise.

Intuitively, average household size and number of children per household are strongly positively correlated, but the literature suggests that these variables have differing impacts on travel behaviour. While household size includes the number of workers likely to commute to work, number of children indicates displacement dependence and, consequently, propensity to rideshare (Rajamani *et al.* 2003). Having more children may also necessitate a larger dwelling. Combined with the cultural desire to raise children in the suburbs, this may indicate greater personal vehicle use.

Both household size and number of children are negatively correlated with the proportion of population over age 18 holding Canadian citizenship, suggesting recent immigrants to Montreal tend to have more children and larger households than Canadian citizens. Average number of children also has a weak positive correlation with proportion of population with neither English nor French as mother tongue. Larger household size, higher Canadian citizenship and lower proportions with unofficial mother-tongue are also associated with higher median after-tax household income and lower unemployment at a 1% significance level. Given the findings of Brownstone (2009) that suggest higher household occupancy is associated with lower dwelling density and higher vehicle use, these demographic characteristics may indirectly affect residential location choices and, consequently, modes of travel.

The spatial input variables can be split into three categories, namely indicators of density, distance and land use. Conventional knowledge of urban geography dictates that one should expect strong correlations among these characteristics, although their formulation in this study yielded somewhat unexpected results (Skaburskis and Mok 2006; Ley and Frost 2006). The dwelling density indicator predictably exhibited a strong negative correlation with linear distance to the central business district. This means that dwelling sizes tend to increase with distance from downtown, a finding consistent with urban land value theory (Skaburskis and Mok 2006). Furthermore, dwelling density and proportion of commercial land use to residential land use positively correlate, suggesting service accessibility may be higher in denser neighbourhoods. Although one would expect larger commercial centers in suburban neighbourhoods, this is overshadowed by the proportionally higher amount of land devoted to single-family residences. Because the proportion was calculated *within* census tracts, it also reflects commercial land use in the direct vicinity of residences. It may therefore help explain travel characteristics for non-work motives. However, the land use data ignores number of floors, type of commercial use and consumer preferences, thus does not fully indicate what is available to nearby residents. Unexpectedly, proportion of park space to residential area correlates only modestly to dwelling density and distance to the central business district. This may suggest a slightly greater accessibility to green-space in low-density suburban neighbourhoods, although the variable does not account for private residential green-space. To summarize, density and distance exhibit a strong negative relationship, while the areal proportion of different land uses show relatively weak relationships to these two factors.

Interpreting correlations between demographic and urban form variables may provide insight into why particular commuting behaviours arise and how this affects the urban carbon cycle. This is particularly important in the context of the present analysis as it helps explain the variable groupings assigned by the factor analysis. As expected, average household size and number of children strongly negatively correlate with the dwelling density indicator. The relationship of dwelling density with median income and unemployment also demonstrates that smaller dwelling sizes, thus denser neighbourhoods, are associated with lower socioeconomic status. Given the previously established negative correlation between income and proportion of population with non-official mother tongue, it is no surprise that the latter also correlates positively with dwelling density.

The strong negative correlation between dwelling density and linear distance to the central business district compels an analysis of the spatial distribution of particular demographic characteristics in Montreal. Household size, number of children and median income modestly positively correlate with the distance indicator, which reflects the typical conception of suburban communities being conducive to family life (Ley and Frost 2006). Negative correlations with unemployment and the non-official language indicator also reflect the high ethnic and socioeconomic diversity of inner-city neighbourhoods (Ibid.).

The land use variables generally correlate modestly with demographic composition variables. Commercial land use proportion correlates negatively, although modestly, with household size, number of children and median income, and positively with unemployment. This suggests that while denser urban neighbourhoods benefit from greater commercial accessibility, many of their inhabitants may have less purchasing power. Interestingly, higher proportions of green-space to residential land use area are also modestly correlated to lower unemployment and higher median income, indicating that neighbourhoods with more public parks may be a privilege of higher-income groups.

The correlation matrix computed in preparation for factor analysis describes expected differences in the spatial and social make-up of urban and suburban neighbourhoods. However, many of the variables considered are highly correlated, which indicates redundancy. The use of factor analysis to create unrelated latent variables is justified by the need to group variables exhibiting strong relationships.

4.2: Interpreting Factor Analysis Output

The principal components factor analysis and rotation yielded three non-correlated factors (Table 4.1; Appendix B). Each factor correlates to a certain degree with the input variables such that a given factor is represented by those inputs having the largest correlations with it. The principal factor is that which correlates most with input variables.

In the present analysis, the principal factor correlates strongly with average household size, unemployment rate, median income, the dwelling density indicator and linear distance to the central business district (Table 4.1). Thus the principal factor is highly representative of the initial variables and can be used to approximate them. The second factor has the strongest correlation with average number of children per household, while the third factor most strongly correlates with the two land use variables. Although the representative power of the latter two factors is significantly lower than that of the principal factor, the previously established importance of the variables they represent reflect the need to include them in further analysis.

Table 4.1: Factor Loadings in Relation to Input Variables

Normalized Input Variables	**Factor Loadings**		
	1	2	3
Average number of children per household	0.296	0.877	-0.084
Average household size	0.683	0.676	-0.095
Unemployment rate	-0.81	0.298	0.02
Median after-tax family income (CAD$)	0.743	0.07	0.153
Proportion of dwellings classified as row-houses, duplexes or apartments	-0.901	-0.237	0.12
Ratio of commercial land use area to residential land use area	-0.286	0.022	0.473
Ratio of park-space land use area to residential land use area	0.262	-0.057	0.824
Linear distance to CBD (km)	0.715	0.085	-0.241
Proportion of population with non-official mother tongue	-0.6	0.615	0.191
Proportion of population over age 18 with Canadian citizenship	0.154	-0.884	0.005

Table 4.1: The highlighted values are the highest correlations between an input variable and an output factor. The corresponding factor can be said to explain the most variation in the original variable. The principal factor, number 1, accounts for the most variation in the original dataset.

Having reduced the number of variables to three, factor analysis greatly simplifies the task of identifying ‘similar’ neighbourhoods. The selection of census tracts based on their deviation from the factor values of the three EPiCC census tracts yielded three groups with significant within-group homogeneity and between-group heterogeneity among input variables (Appendix C). Analysis of variance was performed on the spatial and demographic characteristics of the groups to measure the degree of between-group heterogeneity (Table 4.2; Appendix D).

Table 4.2: ANOVA Results for Heterogeneity between Census Tract Groups

Input Variables	F-Statistic	Significance
Average number of children	6.1	0.002
Average household size	67.9	0.000
Unemployment rate	6.4	0.001
Median after-tax family income	24.2	0.000
Proportion of population with non-official mother tongue	21.5	0.000
Proportion of population over age 18 with Canadian citizenship	11.5	0.000
Proportion of dwellings classified as row-houses, duplexes or apartments	455.8	0.000
Ratio of commercial land use area to residential land use area	13.6	0.000
Ratio of park-space land use area to residential land use area	2.8	0.050
Linear distance to CBD (km)	180.6	0.000

Table 4.2: The significance levels listed above indicate that the null hypothesis of between-group homogeneity for the census tract groups can be rejected for all input variables. Although the park-space variable falls on the threshold of significance, there is sufficient confidence that the groups are statistically different based on the very low significance levels for all other variables.

All tests for homogeneity of variance fall at or below a 5% significance level, which signifies high between-group heterogeneity and reflects the strength of factor analysis for the purposes of this research. Although the factor analysis output was slightly manipulated due to one anomalous urban group census tract, the result of the significance test increases confidence that the census tract groups are appropriately defined. Analysis of variance also confirms that the ‘ideal’ urban group is significantly different from the mathematically defined urban group.

Juxtaposing these two groups allows for a discussion of methodological constraints and biases in studies of urban carbon.

4.3: Characteristics of Neighbourhood Peer Groups

The neighbourhood peer groups exhibit marked differences in urban form (Table 4.3). Increasing distance from the central business district is associated with decreasing dwelling density and land use mix. Between-group demographic characteristics also differ considerably, although their spatial patterning is more complex (Table 4.4). Some unexpected results also point to methodological limitations and challenges for establishing links between these characteristics and CO_2 trends along an urban-exurban gradient.

Table 4.3: Urban Form Characteristics of Census Tract Groups

Urban form characteristics	'Ideal' urban	Urban	Suburban	Exurban
Proportion of dwellings classified as row-houses, duplexes or apartments	99.3%	92.7%	21.7%	11.2%
Ratio of commercial land use area to residential land use area	14.2%	3.6%	2.1%	0.0%
Ratio of park-space land use area to residential land use area	8.6%	17.0%	5.0%	5.0%
Linear distance to CBD (km)	1.7	6.9	19.1	46.8

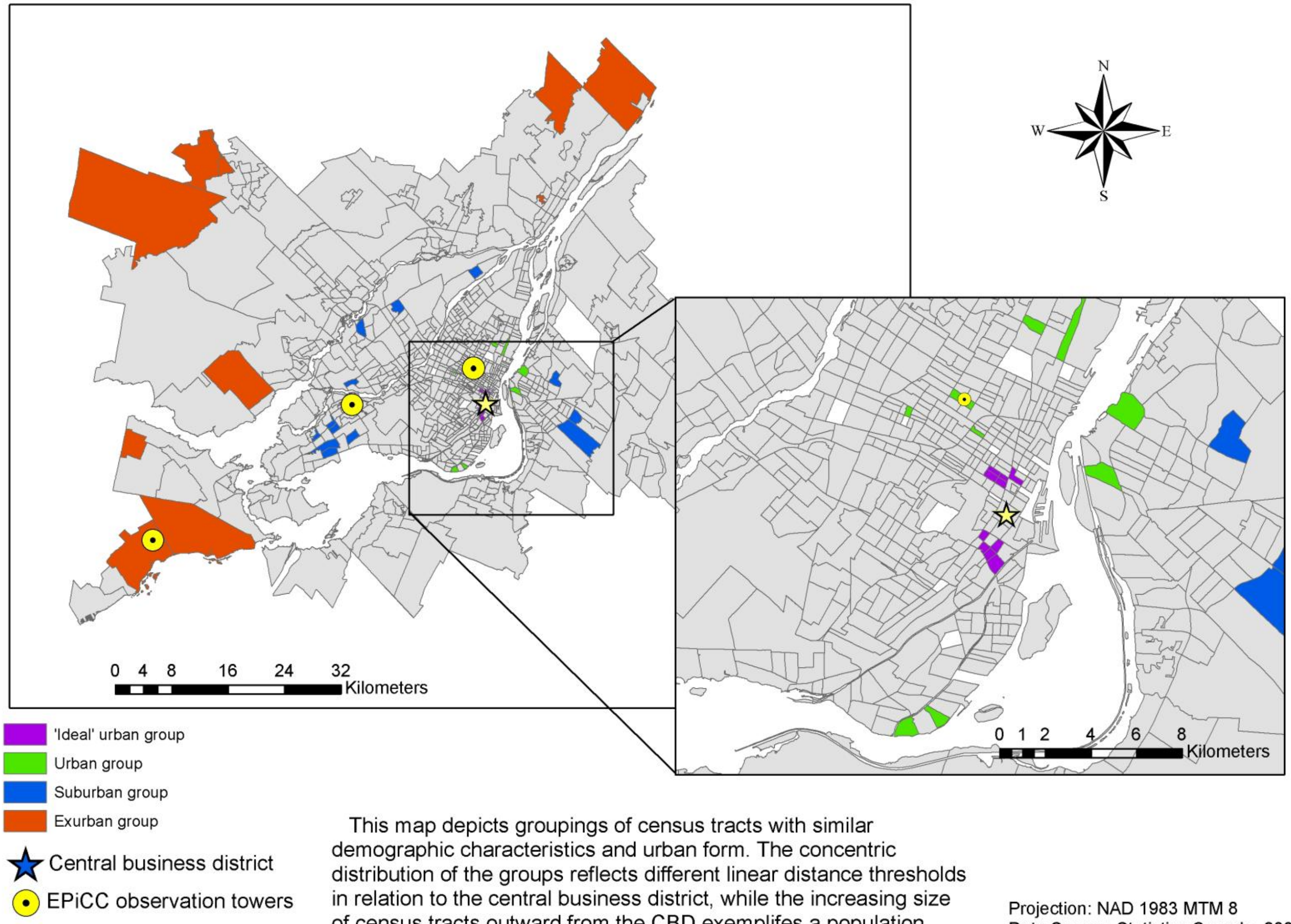
The spatial distribution of the grouped census tracts exhibit a very clear concentric pattern, with census tract areas increasing with distance from the central business district (Figure 4.1). This reflects increasing population dispersal the further a census tract is from the downtown core. Thus, the groups can loosely be identified as urban, suburban and exurban, each of which contains an EPiCC tower. However, one urban census tract clearly exhibited contrasting demographic and spatial characteristics with others of this group and was omitted from further analysis. Accounting for this anomaly, the total number of census tracts in the urban, suburban and exurban groups is 10, 14 and 10, respectively (Appendix E).

The usefulness of the groups for identifying spatial and social drivers of CO_2 emissions largely depends on how they fit into common conceptualizations of urban form. For instance, the urban group has a mean linear distance of 6.9 km from the central business district and 92.7% of its dwellings can be characterized as high-density. As expected, proximity to the downtown core is associated with higher residential densities, while increasing distance is met with a sharp decrease in development density, as seen in the suburban and exurban groups (Table 4.3; Appendix E). Although a mean linear distance of 12.2 km separates the urban and suburban groups, one may argue that the urban EPiCC tower is not located in the "most" urban residential area of Montreal. Given that neighbourhood selection was based on the location of the towers, the entire urban group lies at a relatively large distance from downtown, and in many cases off the Island of Montreal. To surmount this limitation, an idealized group of urban neighbourhoods was selected manually based on distance to the CBD, dwelling densities and knowledge of the Montreal urban fabric ('ideal' urban group).

Table 4.4: Demographic Characteristics of Census Tract Groups

Demographic characteristics	'Ideal' urban	Urban	Suburban	Exurban
Average number of children per household	0.96	0.84	2.90	1.12
Average household size	1.88	1.90	2.81	2.72
Unemployment rate	9.8%	5.6%	4.4%	3.8%
Median after-tax family income (CAD$)	43,441	55,865	68,739	58,137
Proportion of population with non-official mother tongue	33.5%	12.5%	22.2%	1.9%
Proportion of population over age 18 with Canadian citizenship	69.7%	82.2%	72.5%	73.6%

Figure 4.1: Census Tract Groups



This map depicts groupings of census tracts with similar demographic characteristics and urban form. The concentric distribution of the groups reflects different linear distance thresholds in relation to the central business district, while the increasing size of census tracts outward from the CBD exemplifes a population density gradient.

Projection: NAD 1983 MTM 8
Data Source: Statistics Canada, 2006
Mitchell Lavoie, 2009

The dense neighbourhoods found in the “ideal” urban and urban groups house, on average, smaller and lower-income families than the sparser suburban and exurban groups. The advantage of defining an “ideal” urban” group is manifest in its very close proximity to the CBD and significantly higher ethnic diversity, unemployment rate, dwelling density and proportion of commercial to residential space compared to the urban group. It is therefore expected that the origin-destination respondents residing in “ideal” urban census tract group exhibit contrasting travel characteristics to those residing in the urban group. The implications of this predicted difference are complicated by the discovery that urban census tracts have nearly double the proportion of park-space to residential land use that “ideal” urban census tracts have. The role of urban vegetation in mitigating CO_2 emissions must therefore be considered when discussing the carbon-intensity of commuting behaviours.

The “Suburban” group has the largest households, the highest number of children and the highest median household income of all groups. A low proportion of commercial to residential space compared to the “ideal” urban group also suggests potentially lower accessibility to non-work destinations. Given the distance separating these suburban neighbourhoods from the CBD, one must consider how suburbanization influences human behaviour and the built environment. Low dwelling densities imply larger lot sizes and, typically, carbon-sinking residential green-space (Jo and McPherson 1995). The variables incorporated in the factor analysis do not account for vegetation on private property, but the dwelling density indicator reflects the more sparse development patterns in suburbs. The suburban group also exhibits high ethnic diversity, surpassed only by the “Ideal” urban group. Over 20% of its population claims to have neither English nor French mother tongue, which agrees with the well-documented trend toward inner-suburban cultural diversification (Smith 2006).

Both the social and spatial characteristics of the suburban group seem conducive to a car-centric population. The exurban group, on the other hand, is distinguished mainly by its built form. It has by far the lowest dwelling densities and commercial land use, and lies at an average of 46.8 km from the central business district. Unemployment rates are the lowest of all groups, but median family income is below that of the exurban group. Finally, while household size is close to that of the suburban group, households in the exurban group tend to have fewer children. Given these similarities and contrasts, identifying differences in travel mode choices and the spatial patterning of destinations between the suburban and exurban groups will be of particular interest.

Each census tract peer group has a particular set of built form and demographic characteristics that distinguish it from others. While the "ideal" urban and urban groups seem to promote a low-carbon lifestyle, the suburban and exurban groups appear to necessitate higher anthropogenic carbon intensity. However, the sparser built form of the latter two groups may suggest a greater ability to cope with higher carbon dioxide production. Comparing commuting characteristics to trends in CO_2 emissions may concretize this complex relationship.

CHAPTER 5: TRAVEL BEHAVIOUR AND THE URBAN-EXURBAN CO_2 GRADIENT

This section interprets measured CO_2 trends from the EPiCC project in light of known anthropogenic sources, notably urban transportation. It demonstrates how urban form and human activity patterns can help explain seasonal and diurnal observations in CO_2 concentrations and fluxes along an urban-exurban gradient. It also uses urban travel characteristics to suggest how empirical observations of urban carbon must be enhanced with social science collaboration to effectively tackle anthropogenic climate change.

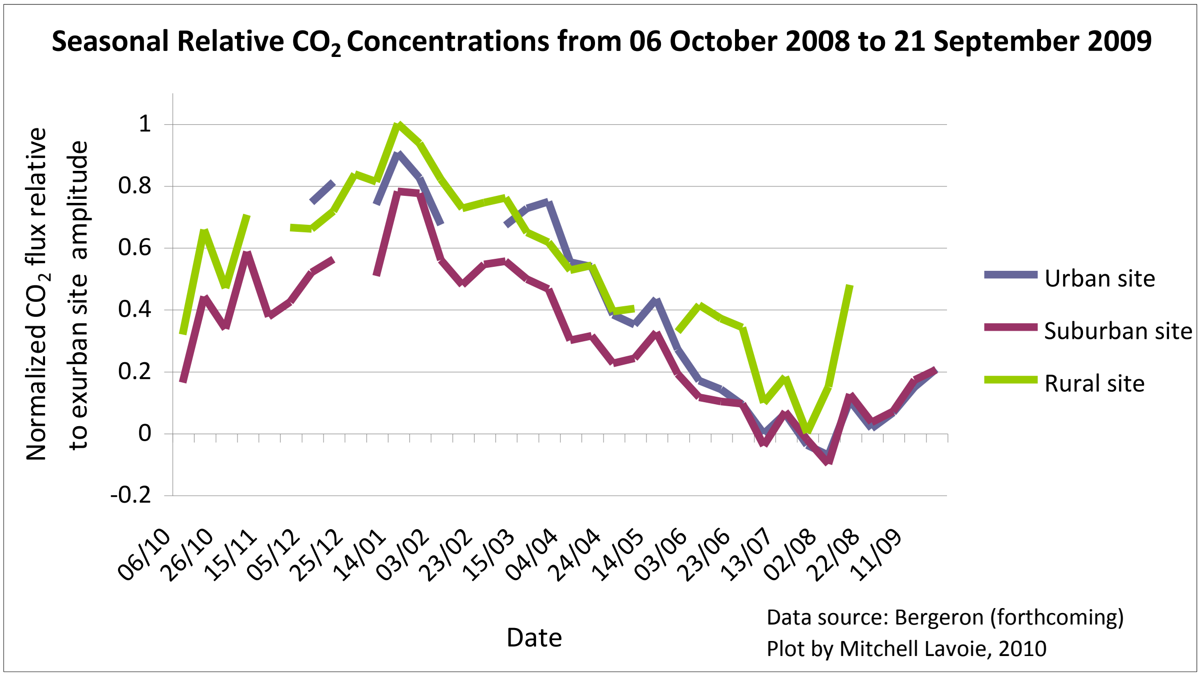
5.1: Interpreting Seasonal and Diurnal CO_2 Trends

To reiterate, the available relative CO_2 trends from the EPiCC observation towers are for 2008 and 2009. The seasonal plots depict measurements from October 2008 to September 2009, and the diurnal plots depict ensemble averages of half-hourly measurements from 15 May to 15 September 2009, and from 15 January to 15 March 2009, respectively. From these graphs, one can draw inferences about how the built and natural environments surrounding the towers influence CO_2 measurements. This section discusses the significance of the primary CO_2 data alongside travel behaviour statistics to obtain a broader understanding of urban carbon. One important note is that the collection periods for the two datasets are separated by five years. Thus, the 2003 origin-destination information must be treated as an indicator of overall trends rather than as the exact circumstances of the period covered by the CO_2 data.

One can deduce from Figure 5.1 that seasonal CO_2 concentrations follow a quasi-sinusoidal trend, with a peak in mid-January and a minimum at the beginning of August, at all EPiCC sites. This is consistent with seasonal cycles of deciduous “greening” in North America.

The sequestration capacity of vegetative cover is reflected in the negative fluxes measured at the suburban and exurban sites during the growing season, as seen in Figure 5.2.

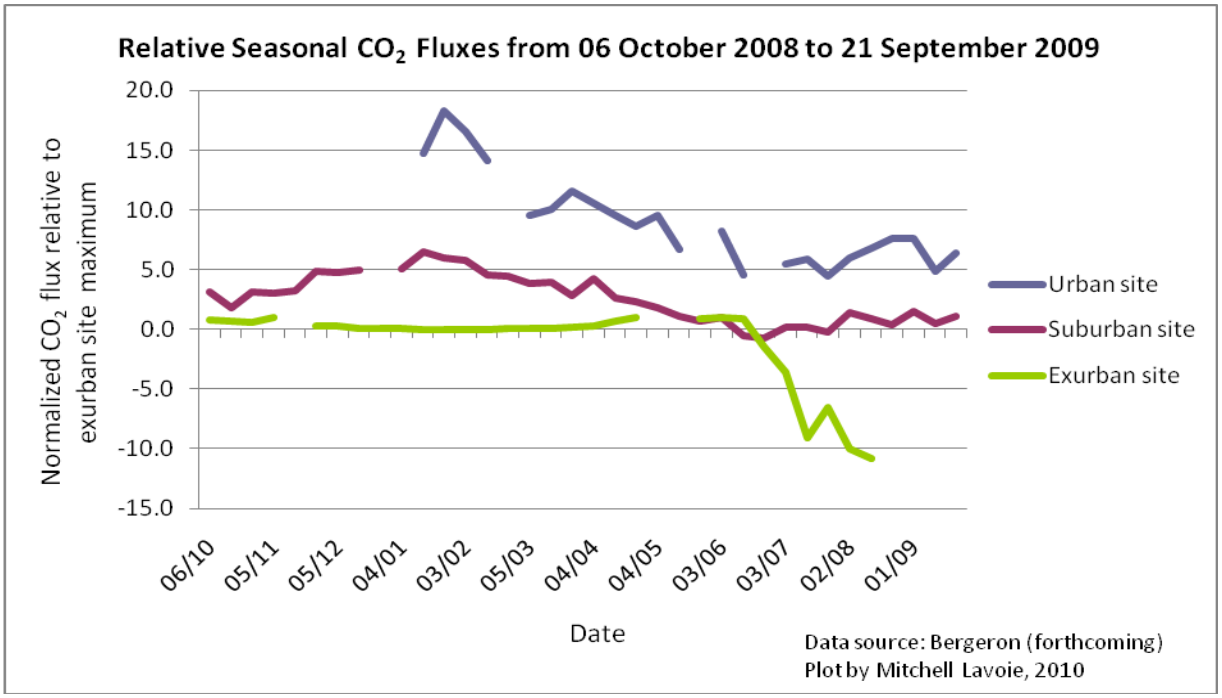
Figure 5.1: Relative Seasonal CO_2 Concentration at the Three EPiCC Sites



Data source: Bergeron (forthcoming)
Plot by Mitchell Lavoie, 2010

The exurban site is a good example of how vegetation and seasonality regulate CO_2 emissions. On an annual basis, the exurban site most often has the highest concentrations, but is nearly carbon neutral during the non-growing season. The consistently higher concentrations measured during summer months reflect soil CO_2 flux triggered by ground decomposer activity (O. Bergeron, pers. comm.). The sinking capacity of crops mitigates this source, however. The seasonality effect is particularly relevant when comparing trends at the urban and suburban sites. While the urban site is consistently a CO_2 source, the suburban site approaches neutrality during summer months. The denser vegetative cover at the latter absorbs CO_2 through photosynthesis, while the former benefits from no such reduction. The difference in CO_2 concentration between these sites is largest during spring months, likely due to “greening up” at the suburban site. Both sites experience maximum positive flux in winter that, in the absence of biogenic processes, can only be explained by the anthropogenic sources such as space heating and vehicle traffic (Ibid.). Although it has been established in Chapter 4 that suburban neighbourhoods typically have larger dwelling units, the combined influence of the built environment is larger at the urban site.

Figure 5.2: Relative Seasonal CO_2 Flux at the Three EPiCC Sites

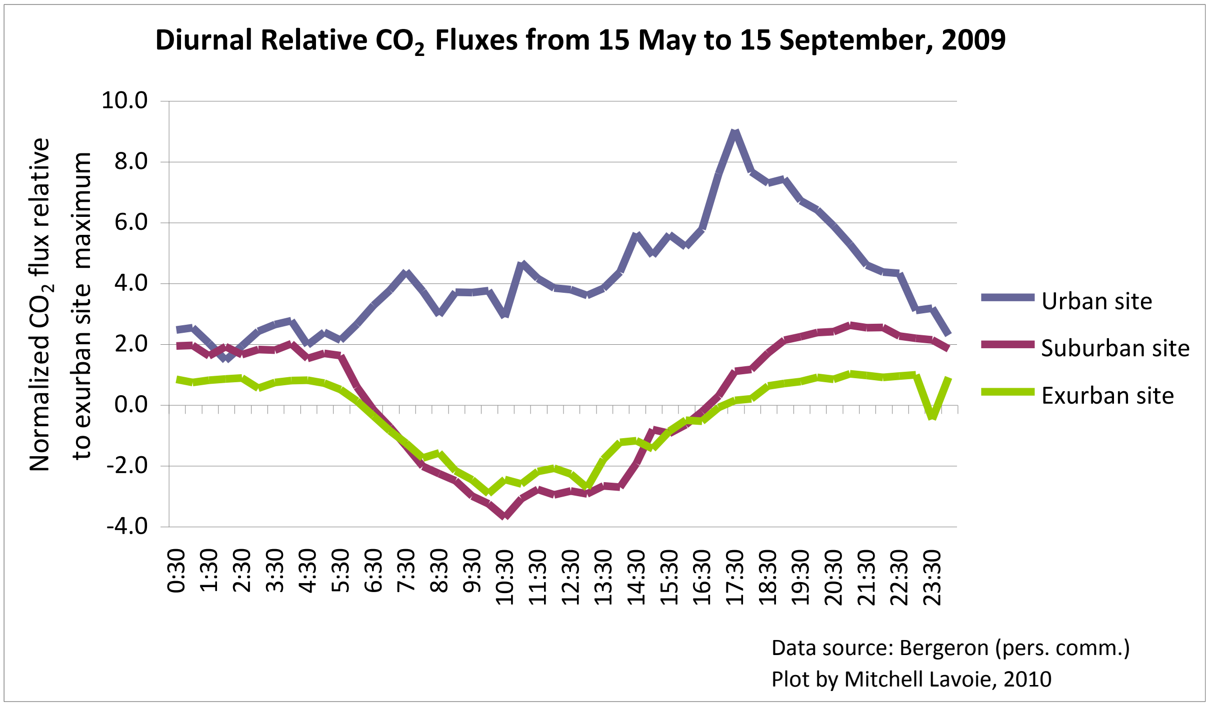


Data source: Bergeron (forthcoming)
Plot by Mitchell Lavoie, 2010

The main conclusion emerging from these data is that CO_2 fluxes and concentrations are most strongly influenced by biogenic processes. However, the effect of stationary anthropogenic sources is reflected in the low carbon sinking capacity of impermeable manmade surfaces at the Urban site and winter residential heating at both the Urban and Suburban sites. The contribution of vehicle traffic to these measurements is far less evident. Reducing the scale of observation to the diurnal level may provide additional insight in this regard.

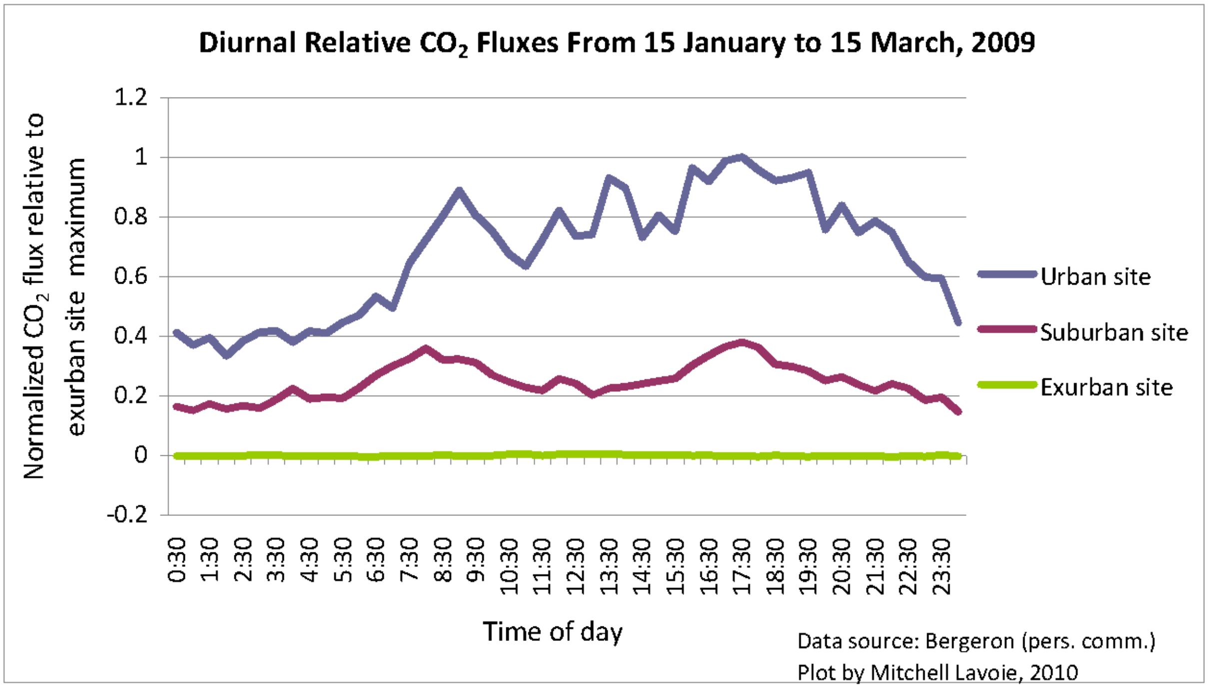
The large difference between winter and summer diurnal fluxes reflects the role of vegetation in offsetting anthropogenic CO_2 emissions. Figure 5.3 shows negative midday fluxes at the suburban and exurban sites, a pattern consistent with seasonal trends. The urban site, on the other hand, is a carbon source throughout the day. This suggests that anthropogenic sources at the urban site far outweigh the sinking capacity of urban vegetation, while the suburban site acts as an effective daytime sink. Grimmond *et al.*'s (1987) observations from Chicago, where it was determined that "the urban surface is always a net source of CO_2," are consistent with the present findings (Ibid., S250). The influence of daily anthropogenic sources is also evident in the winter curves in Figure 5.4, which show both the urban and suburban site as consistent carbon sources throughout the day. In the absence of photosynthetic activity, the higher daytime fluxes can only be explained by anthropogenic emissions.

Figure 5.3: Summer Diurnal CO_2 Flux at the Three EPiCC Sites



The challenge, however, lies in identifying the *sources* of these emissions. Comparing the shapes of the curves to known human activity patterns offers some indication of the culprits. The higher positive flux at the urban site in winter reflects a larger aggregate anthropogenic input from a more densely populated neighbourhood environment. The consistently positive daytime flux at the urban and suburban sites in winter is likely due to residential space heating, and higher midday flux corresponds to typical hours of human activity (Ibid.). The peak in positive flux at the urban site on summer evenings, as well as the dual peaks measured at the urban and suburban sites on winter days, corresponds to rush hour vehicle traffic peaks. Thus, on a diurnal timescale, the anthropogenic drivers of urban carbon dioxide are more evident.

Figure 5.4: Winter Diurnal CO_2 Flux Trends at the Three EPiCC Sites



Data source: Bergeron (pers. comm.)
Plot by Mitchell Lavoie, 2010

The amount of green-space accommodated by the built environment has a large impact on how these emissions are recorded, particularly at the suburban site. The lower dwelling densities in mature neighbourhoods, as captured in the suburban group from the factor analysis, are better carbon sinks than denser urban neighbourhoods. This may be a positive argument for suburban development, but the relative measurements plotted in Figures 5.1 to 5.4 do not indicate how much CO_2 is being generated *per capita* around the sites or which human activities are most responsible for anthropogenic emissions. CO_2 observations must then be interpreted alongside indicators of carbon-intensive behaviour, namely commuting patterns and preferences.

5.2: Urban Travel Characteristics among Neighbourhood Groups

Given the evident anthropogenic impact on diurnal and seasonal CO_2 trends, the next step is to identify spatial patterns in carbon-intensive human behaviour. Interpreting differences in commuting behaviour between census tract groups and understanding how built and social characteristics interact to affect these behaviours may elucidate the anthropogenic component of the urban carbon cycle. Comparing results to past research might also reveal a consistency in overall trends and increase the robustness of the present findings.

Holtzclaw *et al.* (2002) suggest that access to private vehicles means a greater propensity to use them. Figure 5.5 demonstrates this phenomenon is present in Montreal. An increase in number of vehicles per household is clearly associated with an increase in the number of displacements made along an urban-exurban gradient. The suburban group has a level of vehicle ownership nearly twice that of the "ideal" urban group and generates nearly 50% more displacements per household. The exurban group also exhibits high vehicle ownership, but makes approximately 20% fewer displacements per household than the suburban group. Notable similarities and differences in number and spatial dispersion of displacements between groups can be seen in Figure 5.9. A common feature of the "ideal" urban, urban and suburban groups is a strong clustering of destination points around the central business district of Montreal. Central neighbourhoods receive an influx of vehicles from outlying areas as people travel to work, but evening destinations reflect the higher mean distance of the suburban group from the central business district. However, destination points from the exurban group show travel to smaller regional nodes beyond the urban fringe, such as Saint-Jérôme to the northwest and Repentigny to the northeast. This may have significant implications for travel mode choices and limits, particularly in the case of public transit provision.

Figure 5.5: Vehicle Ownership and Trip Generation

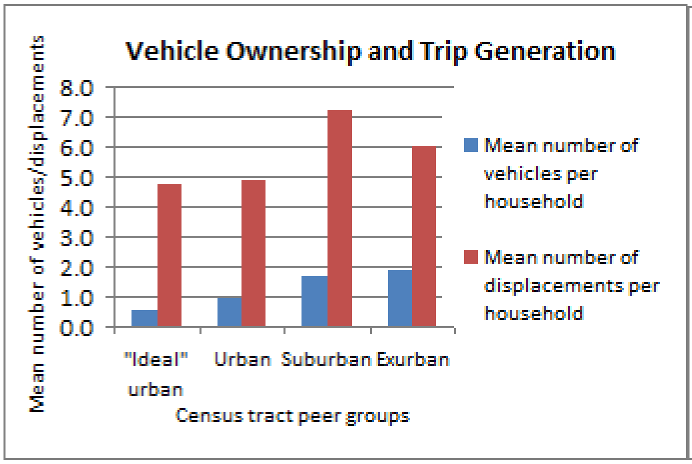


Figure 5.6: Driving Trips and Dwelling Density

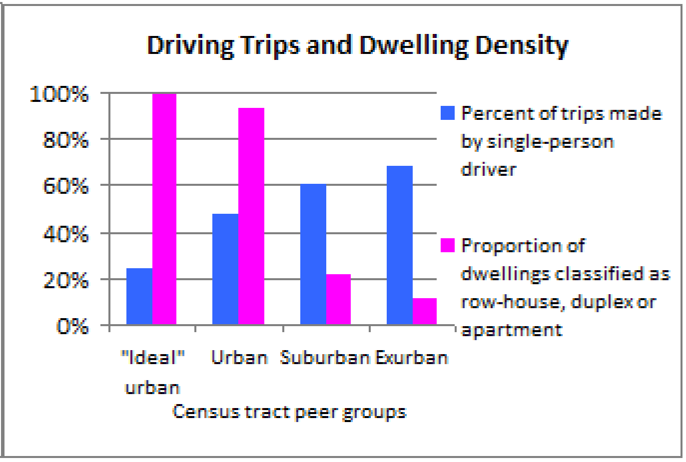


Figure 5.7: Shopping Trips and Commercial Land Use Area

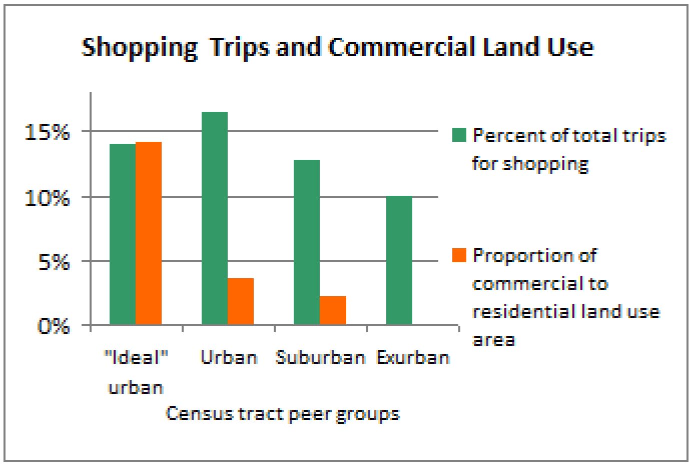


Figure 5.8: Modal Split for the First Leg of Displacements

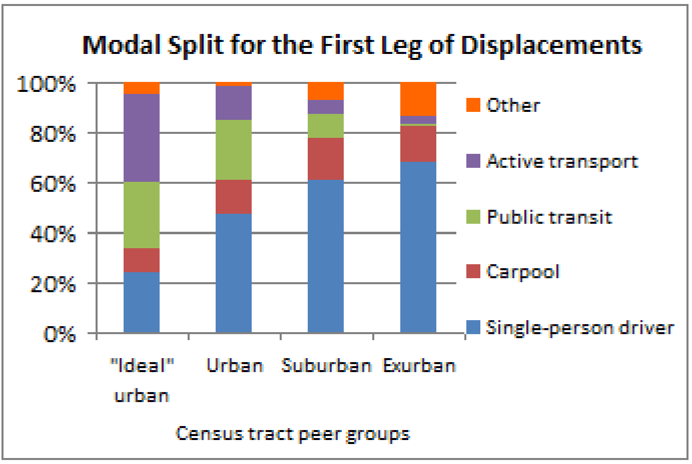
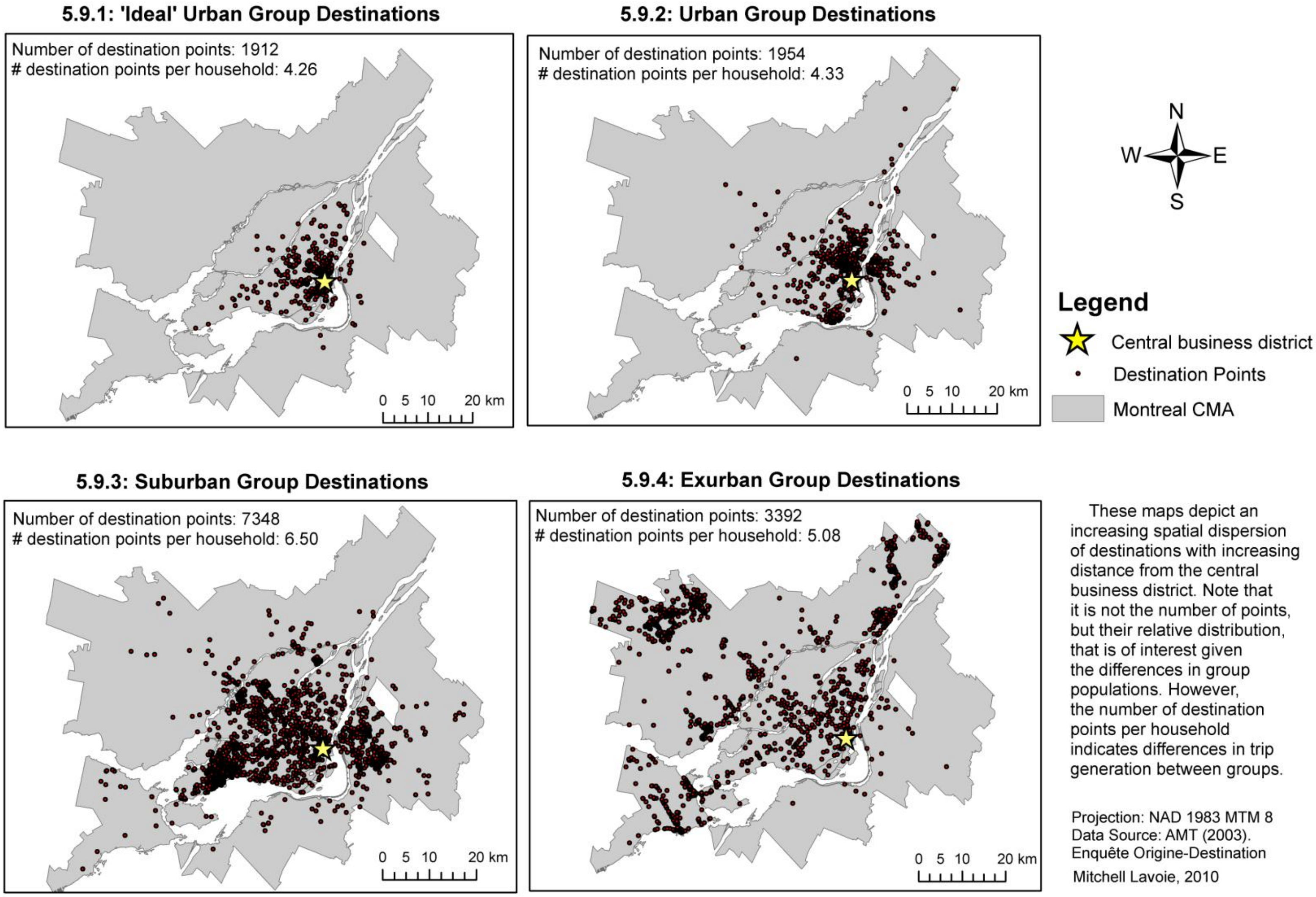


Figure 5.9: Spatial Dispersion of Destinations by Census Tract Group



5.9.1: 'Ideal' Urban Group Destinations

5.9.2: Urban Group Destinations

5.9.3: Suburban Group Destinations

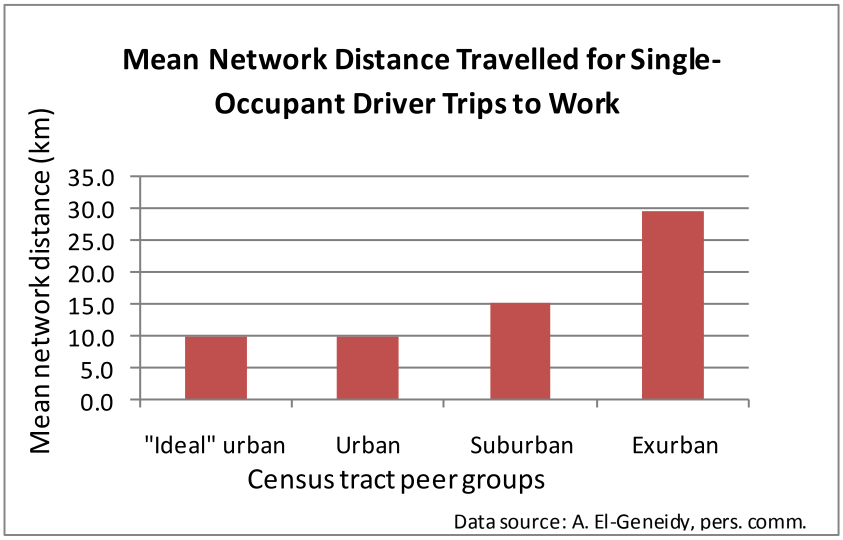
5.9.4: Exurban Group Destinations

These maps depict an increasing spatial dispersion of destinations with increasing distance from the central business district. Note that it is not the number of points, but their relative distribution, that is of interest given the differences in group populations. However, the number of destination points per household indicates differences in trip generation between groups.

Projection: NAD 1983 MTM 8
Data Source: AMT (2003). Enquête Origine-Destination
Mitchell Lavoie, 2010

Given these trip generation and destination characteristics, the next logical steps are to observe the proportion of displacements made by personal vehicles and suggest potential social and geographic reasons for this mode preference. Figure 5.6 expresses a strong relationship between dwelling density and single-occupant vehicle displacements. While the "ideal" urban and urban groups have high residential densities and low relative single-occupant vehicle displacements, the opposite is seen in the suburban and exurban groups. This suggests that low densities either encourage or force more vehicle use. Another spatial driver of private vehicle displacements is illustrated in Figure 5.3, which suggests that people inhabiting exurban group census tracts make fewer non-work trips, presumably due to lower access to commercial services. The "ideal" urban group benefits from an abundance of nearby businesses and clearly sees more trips generated as a result, while people living long distances from the nearest amenities are more likely to reach them by car (Figure 5.6; Figure 5.10).

Figure 5.10: Mean Network Distance Travelled for Single-Occupant Driver Trips to Work



Data source: A. El-Geneidy, pers. comm.

Figure 5.10: Network distances were calculated using ArcGIS Network Analyst on the origin and destination points of the households lying within the census tract groups (Network distance dataset provided by A. El-Geneidy, pers. comm.).

The social characteristics of the suburban and exurban groups may also suggest why they exhibit higher private vehicle ownership and use. There is an approximately 30% difference in driver’s license holding between the “ideal” urban and exurban groups, which reflects either a disparity in access or a difference of interest in regard to driving. Larger household sizes, and particularly more children, among suburban and exurban group census tracts may also increase the desire to own a vehicle. The higher median incomes among these groups are also permissive of vehicle ownership, but the decision to own a vehicle likely occurs in unison with residential location choices. These factors may create a desired dependence on private vehicles for displacements (Handy *et al.* 2005b).

Although consumer preference may blur the relationship between urban form and travel decisions, Figure 5.8 shows that the use of modal alternatives varies with distance from the central business district. A decreasing proportion of displacements are made by public transit with increasing distance from the central business district and decreasing residential density. Lower population densities cannot support frequent public transit service, which compels people to drive. Suburban and exurban group residents also walk and bicycle less than their urban counterparts, suggesting that density has a strong influence on the proportion of trips made by single-occupant driving.

To summarize, low-density residential development and long distances to the central business district appear to be strongly associated with private vehicle use and trip generation, a relationship most evidently manifest in the suburban and exurban groups. The “ideal” urban and urban groups show far fewer displacements and demonstrate greater use of public transit and active modes of transportation. Different modes and frequencies of displacement have been linked to varying levels of greenhouse gas output and, therefore, must be acknowledged as anthropogenic drivers of CO_2 in urban environments (Ewing *et al*. 2008).

Knowledge of CO_2 production from vehicles suggests that analyzing commuting characteristics is an important component of research on anthropogenic CO_2 in cities. These behaviours, along with the factors influencing them, then become critical to our understanding of the urban carbon cycle. The following section explains how the relationship between urban form, demographic characteristics and travel behaviour helps explain trends in CO_2 emissions measured at the three EPiCC sites.

5.3: Social Underpinnings of the Urban-Exurban CO_2 Gradient

The CO_2 measurements from the three EPiCC sites are indicative of the stationary emission sources and sinks, both natural and anthropogenic, in the immediate vicinity each tower (O. Bergeron, pers. comm.). The urban travel literature, notably Ewing *et al.* (2008), presents compelling evidence that vehicle emissions are also a large contributor to urban anthropogenic carbon, which necessitates a distinction between stationary and mobile sources. The shape of the built environment, and population behaviours in response to it, then become of critical importance.

The data collected for the EPiCC project clearly indicate that urban carbon concentration and flux are dependent on urban form. The concentration of emitted carbon dioxide increases from the exurban hinterland of Montreal to more centrally located neighbourhoods along a gradient of increasing development. The built environment and the carbon-intensive human activities it harbours play a large role in this pattern, as evidenced in Figures 5.1 to 5.4.

The “ideal” urban and urban groups exhibit greater use of less carbon-intensive transport modes, such as public transit and active transport, and generate fewer displacements than the more distant groups. However, the seasonal CO_2 concentration and diurnal flux curves indicate that urban neighbourhoods have both more ambient carbon dioxide and less carbon sinking capacity than suburban and exurban areas. Andrews (2008) notes a similar pairing of less carbon-intensive travel choices and lower carbon sequestration in dense urban neighbourhoods. Density and low vegetative coverage may play a large role in the magnitude of urban site CO_2 emissions, but rush hour traffic congestion likely explains the morning and evening peaks seen in Figures 5.3 and 5.4. Employment locations and the resulting travel patterns of people living further away therefore contribute to measured CO_2 levels in urban neighbourhoods.

The origin and nature of mobile sources of CO_2 cannot be deduced from data collected at stationary measurement sites. Spatial analysis of travel behaviour is therefore vital to our understanding of the drivers of urban carbon. While the CO_2 measurements reflect the positive impact of suburban and exurban vegetation on the carbon balance, the computed travel statistics show that these types of neighbourhoods foster private vehicle dependence. Reckien *et al.* (2007) note similar findings, which suggest that higher income, as seen in the suburban group, leads to greater mobility in urban environments. Greater mobility, in turn, brings employment centers within reach of distant suburban and exurban neighbourhoods.

Displacements originating in the suburban group have destinations throughout the Montreal metropolitan area (Figure 5.9). However, the mean network distance for single-occupant car trips to work from this group is slightly over 15 km (Figure 5.10). This is only an approximately 5 km greater mean distance than car trips from the “ideal” urban and urban groups. While more suburban-group residents opt for driving, the relatively small difference in distance travelled between the urban and suburban groups indicates that urban residents may not necessarily work downtown (Figure 5.8). Behan *et al.* (2008) demonstrate that a growing tendency toward polycentric metropolitan employment centers and reverse commuting greatly complicate public transit provision (Behan *et al.* 2008). The industrial employment pole around the Montréal-Trudeau Airport is a case in point. The choice or necessity to drive may therefore result from employment location rather than residential location in the metropolitan area.

In contrast, exurban neighbourhoods have the highest modal share of single-occupant driving and the greatest distance travelled for car trips to work (Figure 5.10). Despite more carbon-intensive human activity per capita, the CO_2 fluxes measured at the exurban EPiCC site mainly capture non-anthropogenic sources. Of further concern is the negligible use of public transit among this group (Figure 5.8). While the suburban group has some access to and uses public transit to a small degree, the exurban group appears to have no viable alternative to driving. Popular destinations for displacements from the exurban group reach far beyond the central business district, which calls for new ways of thinking about servicing low-density areas with public transit.

These spatial disparities between measured CO_2 levels and carbon-intensive behaviour suggest a need for careful interpretation of evidence, particularly when informing policy. Greater attention must be paid to how the composition and use of the built environment affects CO_2 measurements, particularly when comparing distant residential neighbourhoods to urban mixed-use nodes. Urban, suburban and exurban differences in commuting characteristics demonstrate how the main culprits of carbon-intensive behaviour may not reside where the highest CO_2 emissions are recorded.

CHAPTER 6: (RE)-CONCEPTUALIZING URBAN CARBON

The contrast between suburban carbon sinking capacity and suburban carbon-intensive behaviour suggest that a change is needed in the way we think about urban form and anthropogenic greenhouse gas emissions. Although higher-density neighbourhoods near the central business district of Montreal were shown to harbour less carbon-intensive modes of transport, these neighbourhoods may be constant carbon sources. Employment location might then determine how people travel and, consequently, how much CO_2 they emit and where it is emitted. Exurban commuting, for instance, presents a distinct problem sprouting from a lack of alternatives to driving and scattered activity centers. Focusing on travel behaviour revealed that an interdisciplinary approach is needed in studies of urban carbon, both to define appropriate research methods and to obtain a multifaceted interpretation of the problem in preparation for policy formulation.

While comparing measured CO_2 to travel statistics may offer a new perspective on urban carbon, there are many additional factors to consider. Several authors identify methodological shortcomings and considerations that complicate the interpretation of findings, particularly in social science studies of natural phenomena. Handy *et al.* (2005) comments on the high potential for spurious relationships between social and geographic variables in travel behaviour studies, which necessarily complicates the task of conceptualizing the urban carbon cycle. While the present research sheds light on the spatial patterning of carbon-intensive human behaviour in Montreal, it can only hypothesize why this pattern exists.

Confounding factors not captured by this research include meteorological conditions, differences in vehicle type and size, and variability in driving conditions (high-speed highway driving versus stop-and-go traffic) (Marquez and Smith 1999; Stone 2007). These technical variables undoubtedly introduce uncertainty into the previously hypothesized relationships between urban form, travel behaviour and CO_2 emissions. With the exception of vehicle type, these variables are either difficult or impossible to predict and modify. One must then inquire whether they compromise the value of the overarching finding that carbon-intensive commuting behaviour originates in neighbourhoods with lower measured CO_2 levels.

It is also worth noting that this research was carried out from a human geography perspective and that the "language" of social and natural scientists differ. Attempting to interpret urban carbon from both conceptual fields is inevitably daunting and cannot account for all considerations among disciplines. Therefore, studying anthropogenic drivers of climate change in cities requires interdisciplinary collaboration. Focusing on behavioural drivers at the aggregate neighbourhood level, given the empirically measured urban-exurban CO_2 gradient, may open up new short-term policy directions.

CO_2 emissions must be reduced to stabilize atmospheric concentrations and mitigate the negative impacts of climate change on human wellbeing (Forster *et al.* 2007). Human activity makes an ever-growing contribution to the carbon cycle as urban mobility gives way to carbon-intensive behaviour. Understanding the anthropogenic inputs to the urban carbon cycle and the physical and social factors that influence them is therefore vital to the effort against dangerous climate change.

Current transport and development pricing indirectly subsidize highway construction and low-density built environments (Ewing *et al.* 2008). When people make their travel and residential location decisions, they are constrained by what is available to them. If urban populations are expected to reduce their anthropogenic greenhouse gas contributions, less carbon-intensive options must be provided (Ibid.). Identifying built-form and social correlates of travel behaviour guides the process of discovering these options.

This research demonstrates that change is needed in the way we conceptualize suburbia in relation to carbon intensity. As the CO_2 flux curves demonstrate, low-density suburban and exurban neighbourhoods are effective daytime carbon sinks during the growing season. However, the commuting characteristics of populations inhabiting these areas reflect high vehicle use over long distances, which contribute to a portion of the urban carbon cycle not captured by stationary measurement stations. While measured positive CO_2 flux increases with proximity to the central business district, the carbon intensity of displacements increases in the opposite direction. Low-density neighbourhoods therefore benefit from higher carbon sequestration, yet foster high vehicle use over long distances. This means that the "price tag" of carbon dioxide emissions is higher for dense urban neighbourhoods, which attract displacements from outlying areas without having the sequestration capacity to mitigate them.

The disagreement between stationary CO_2 measurements and the culprits of carbon-intensive behaviour warrants greater attention. Researchers and policy-makers must interpret measured emissions alongside their anthropogenic drivers, both stationary and mobile, to encourage people to reduce their carbon footprint. A focus on transportation mode choices indicates the potential for short-term mitigation strategies, such as suburban public transit improvements and higher taxes on vehicle use (Ewing *et al.* 2008). Incentives to purchase homes in more central neighbourhoods may also have positive spin-offs for urban carbon reduction as the gap between residential and employment location is reduced. In 2010, the City of Montreal implemented such a policy, targeting starter families looking to purchase their first home (Ville de Montréal 2010). While these policies attempt to promote more carbon-neutral lifestyle choices, there is an inevitable lag between implementation and subsequent impacts. The decreasing predictability and increasing geographic reach of trip destinations, as evidenced in Figure 5.9, also indicates that transportation policy reform may be more viable than urban densification.

This research also sets the foundation for more in-depth discussions of the relationship between anthropogenic greenhouse gas emissions and urban form. For instance, can people continue to pursue the dream of inhabiting verdant suburban landscapes while being stewards of environmental sustainability if transportation policy encourages low-carbon modes? Alternatively, how can dense urban environments be retrofitted to increase their carbon sequestration capacity? To answer these questions, researchers must approach the science of urban greenhouse gas emissions with knowledge of how the built environment both contributes directly to these emissions and subsidizes energy-intensive behaviour. Only then can effective policies be implemented to mitigate anthropogenic climate change from urban environments.

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Format: DBF table with x-y coordinates of origins and destinations and numerically coded attributes for displacements in the Montreal CMA

DMTI Spatial, Inc. (2008). Quebec Land Use. Accessed via the McGill University Geographic Information Center
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Geographic coordinate system: GCS NAD 1983
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Top-Bottom: 52.831881 to 45.068549

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Format: Excel table with Census Tract ID codes for the Montreal CMA (462)

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Format: Shapefile feature class
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APPENDIX A: PEARSON CORRELATION MATRIX OF STANDARIZED DEMOGRAPHIC AND URBAN FORM VARIABLES

		Avg. # Children/ household	Avg. Household size	Unemployment rate	Median Family Income	Dwellng Density indicator	Com/res Land use ratio	Parks/res Land use ratio	Linear Distance To CBD	% Non-official Mother tongue	citizen_norm
Avg. # children/household	Pearson Correlation	1	.801(**)	.018	.237(**)	-.441(**)	-.100(**)	-.028	.267(**)	.281(**)	-.662(**)
	Sig. (2-tailed)	.	.000	.606	.000	.000	.003	.420	.000	.000	.000
	N	860	860	860	860	860	860	860	860	860	860
Avg. household size	Pearson Correlation	.801(**)	1	-.362(**)	.509(**)	-.803(**)	-.182(**)	.040	.538(**)	.008	-.432(**)
	Sig. (2-tailed)	.000	.	.000	.000	.000	.000	.247	.000	.810	.000
	N	860	860	860	860	860	860	860	860	860	860
Unemployment rate	Pearson Correlation	.018	-.362(**)	1	-.624(**)	.609(**)	.164(**)	-.099(**)	-.428(**)	.590(**)	-.355(**)
	Sig. (2-tailed)	.606	.000	.	.000	.000	.000	.004	.000	.000	.000
	N	860	860	860	860	860	860	860	860	860	860
Median family income	Pearson Correlation	.237(**)	.509(**)	-.624(**)	1	-.603(**)	-.155(**)	.145(**)	.261(**)	-.295(**)	.041
	Sig. (2-tailed)	.000	.000	.000	.	.000	.000	.000	.000	.000	.232
	N	860	860	860	860	860	860	860	860	860	860
Dwelling density indicator	Pearson Correlation	-.441(**)	-.803(**)	.609(**)	-.603(**)	1	.233(**)	-.109(**)	-.711(**)	.411(**)	.050
	Sig. (2-tailed)	.000	.000	.000	.000	.	.000	.001	.000	.000	.145
	N	860	860	860	860	860	860	860	860	860	860
Com/res land use ratio	Pearson Correlation	-.100(**)	-.182(**)	.164(**)	-.155(**)	.233(**)	1	-.014	-.193(**)	.215(**)	-.025
	Sig. (2-tailed)	.003	.000	.000	.000	.000	.	.679	.000	.000	.471
	N	860	860	860	860	860	860	860	860	860	860
Parks/res land use ratio	Pearson Correlation	-.028	.040	-.099(**)	.145(**)	-.109(**)	-.014	1	.077(*)	-.074(*)	.069(*)
	Sig. (2-tailed)	.420	.247	.004	.000	.001	.679	.	.024	.031	.044
	N	860	860	860	860	860	860	860	860	860	860
Linear distance to CBD	Pearson Correlation	.267(**)	.538(**)	-.428(**)	.261(**)	-.711(**)	-.193(**)	.077(*)	1	-.437(**)	.027
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.024	.	.000	.421
	N	860	860	860	860	860	860	860	860	860	860
% Non-official mother tongue	Pearson Correlation	.281(**)	.008	.590(**)	-.295(**)	.411(**)	.215(**)	-.074(*)	-.437(**)	1	-.547(**)
	Sig. (2-tailed)	.000	.810	.000	.000	.000	.000	.031	.000	.	.000
	N	860	860	860	860	860	860	860	860	860	860
% Canadian citizens	Pearson Correlation	-.662(**)	-.432(**)	-.355(**)	.041	.050	-.025	.069(*)	.027	-.547(**)	1
	Sig. (2-tailed)	.000	.000	.000	.232	.145	.471	.044	.421	.000	.
	N	860	860	860	860	860	860	860	860	860	860

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

APPENDIX B: FACTOR ANALYSIS STATISTICS

Communalities

	Initial	Extraction
Avg_chil_norm	1.000	.864
avgpershh_norm	1.000	.933
unemp_norm	1.000	.745
medincome_norm	1.000	.580
dweldens_norm	1.000	.883
comres_norm	1.000	.306
parksres_norm	1.000	.750
distCBD_norm	1.000	.577
lang_norm	1.000	.774
citizen_norm	1.000	.806

Extraction Method: Principal Component Analysis.

Total Variance Explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.725	37.255	37.255	3.725	37.255	37.255	3.618	36.182	36.182
2	2.478	24.783	62.038	2.478	24.783	62.038	2.547	25.473	61.655
3	1.012	10.122	72.160	1.012	10.122	72.160	1.051	10.505	72.160
4	.914	9.139	81.299						
5	.789	7.891	89.189						
6	.314	3.142	92.332						
7	.281	2.807	95.138						
8	.261	2.614	97.752						
9	.172	1.718	99.470						
10	.053	.530	100.000						

Component Matrix(a)

	Component		
	1	2	3
Avg_chil_norm	.505	.780	-.015
avgpershh_norm	.831	.492	.009
unemp_norm	-.711	.485	-.059
medincome_norm	.714	-.114	.238
dweldens_norm	-.939	-.013	.008
comres_norm	-.326	.086	.438
parksres_norm	.141	-.128	.845
distCBD_norm	.738	-.087	-.156
lang_norm	-.454	.739	.146
citizen_norm	-.063	-.895	-.013

Extraction Method: Principal Component Analysis.
3 components extracted.

Rotated Component Matrix(a)

	Component		
	1	2	3
Avg_chil_norm	.296	.877	-.084
avgpershh_norm	.683	.676	-.095
unemp_norm	-.810	.298	.020
medincome_norm	.743	.070	.153
dweldens_norm	-.901	-.237	.120
comres_norm	-.286	.022	.473
parksres_norm	.262	-.057	.824
distCBD_norm	.715	.085	-.241
lang_norm	-.600	.615	.191
citizen_norm	.154	-.884	.005

Extraction Method: Principal Component Analysis.
Rotation Method: Equamax with Kaiser Normalization.
Rotation converged in 4 iterations

Component Score Coefficient Matrix

	Component		
	1	2	3
Avg_chil_norm	.053	.337	-.034
avgpershh_norm	.168	.246	-.020
unemp_norm	-.238	.142	-.037
medincome_norm	.222	.011	.211
dweldens_norm	-.241	-.065	.038
comres_norm	-.044	.030	.440
parksres_norm	.143	-.008	.825
distCBD_norm	.182	.007	-.176
lang_norm	-.173	.266	.155
citizen_norm	.070	-.355	-.006

Extraction Method: Principal Component Analysis. Rotation Method: Equamax with Kaiser Normalization

Component Score Covariance Matrix

Component	1	2	3
1	1.000	.000	.000
2	.000	1.000	.000
3	.000	.000	1.000

Extraction Method: Principal Component Analysis. Rotation Method: Equamax with Kaiser Normalization

APPENDIX C: EXAMPLE OF THE CENSUS TRACT SELECTION PROCEDURE

Figure 1: Factor Loadings falling within ¼ standard deviations from that of the urban site's census tract (205)

Figure 1: This table orders the factor loadings that fall within ¼ standard deviations from the loading of the census tract containing the urban EPiCC site (CT 205 – in bold). If a census tract meets this criterion for all three factors, it is considered similar to the census tract in which the urban site is located (highlighted). This procedure was repeated for the suburban and exurban sites, yielding three groups of census tracts with different spatial and demographic characteristics.

CT 205 (Urban site)					
CTID	Factor 1	CTID	Factor 2	CTID	Factor 3
1	-0.19162	1	-1.17103	10	0.12582
2	-0.25716	4	-1.14085	11	-0.0659
3	-0.18176	5	-1.22514	12.02	-0.14617
4	-0.25166	7	-1.07114	16	-0.20345
5	-0.2946	10	-1.30443	18	0.23553
6	-0.26123	13	-1.28715	21	-0.22006
7	-0.23722	28	-1.24353	22	-0.20821
8	-0.09199	29	-1.17306	23	-0.16153
9	-0.33833	32	-1.28603	28	-0.13421
10	-0.23201	35	-1.42415	29	0.07857
11	-0.14909	37	-1.45041	36	-0.09553
18	-0.50027	46	-1.34801	37	0.19982
55.01	-0.4893	61	-1.07083	38	-0.00647
70	-0.17197	62	-1.25252	42	0.11852
80	-0.42762	63	-1.04544	44	0.06299
98	-0.15135	86	-1.15013	45	-0.11115
99	-0.39018	88	-1.06101	49	0.25606
102	-0.34052	133	-1.22546	50	-0.11751
105	-0.16513	140	-1.22394	51	0.2362
106	-0.25479	141	-1.28259	52	0.25131
115.01	-0.32403	144	-1.24127	53	0.20396
126	-0.43213	146	-1.51909	58	0.06006
134	-0.44968	147	-1.25477	63	0.06396
138	-0.48409	149	-1.36386	66.01	0.19669
140	-0.18481	151	-1.51548	73	-0.01554
141	-0.20401	152	-1.40714	75	-0.16403
148	-0.33954	155	-1.48527	77	0.0039
157	-0.48966	159	-1.17191	79	-0.10788
169	-0.33018	160	-1.31651	80	-0.0161
174	-0.30789	162	-1.11692	81	-0.18176
175	-0.50302	171	-1.20105	83	-0.1227
176	-0.4332	172	-1.30805	84	0.13719
190.01	-0.26154	173	-1.50215	86	-0.16018
191	-0.14002	174	-1.46015	89	-0.0732
193	-0.06287	175	-1.13196	93	0.2518

194	-0.02561	178	-1.49849	94.01	-0.10203
195.01	-0.43542	179	-1.10495	95	-0.16244
196	-0.42959	182	-1.15159	96	-0.12212
205	**-0.26296**	183	-1.50365	97.01	-0.143
206	-0.28641	187.02	-1.06475	98	-0.06478
226	-0.40226	188.02	-1.06059	99	-0.061
227	-0.45019	190.01	-1.33059	100	-0.0347
235	-0.43551	**205**	**-1.29196**	101.01	-0.01979
237	-0.50213	206	-1.08013	102	-0.03593
244	-0.47916	208	-1.14159	105	0.07186
264.01	-0.20713	210	-1.06458	106	0.11397
264.02	-0.278	211	-1.23485	107	-0.12078
265	-0.38656	212	-1.25849	109	0.03266
280	-0.38581	215	-1.17765	110	0.12954
281	-0.06669	227	-1.31523	111	-0.00513
287.02	-0.24991	235	-1.40265	112.01	-0.0206
290.01	-0.30352	236	-1.13249	112.02	0.14973
290.03	-0.29232	247	-1.20443	114	-0.09682
290.05	-0.39964	314	-1.19507	115.01	0.09764
290.07	-0.18603	322.04	-1.09326	115.02	0.00643
309	-0.14081	323	-1.15802	116	-0.04687
310	-0.43558	390	-1.16625	117	0.02215
312	-0.43776	392	-1.36133	118	-0.03939
314	-0.31547	512.03	-1.33429	121	0.14017
317.01	-0.03738	580.02	-1.23137	123	-0.16456
317.02	-0.25905	582.01	-1.06706	124	0.24968
320	-0.19561	593	-1.36191	125	-0.09366
322.03	-0.43808	627	-1.04204	126	0.02081
322.04	-0.06722	635	-1.21419	127.01	-0.03334
323	-0.12837	677.02	-1.19158	132	0.18923
325.01	-0.46818	693	-1.05822	144	0.02087
330	-0.43317	700.01	-1.19019	146	0.06193
351	-0.31176	705.02	-1.43344	147	0.06567
352	-0.31008	783	-1.31196	149	-0.19885
361	-0.45205	784	-1.05598	150	0.02784
363	-0.35523	788	-1.13747	151	-0.17674
365	-0.27035	827.02	-1.31172	153	-0.18746
367	-0.2146	857.08	-1.44101	154	-0.09855
380	-0.24178	862	-1.06701	156	-0.05972
383.02	-0.48507	863.02	-1.21395	157	0.01947
391	-0.22775	865	-1.17077	158	0.11685
393	-0.10193	879.01	-1.21159	159	-0.00493

394	-0.21982	879.02	-1.12184	160	0.20209
395.03	-0.37066	882	-1.10555	161	0.15548
402	-0.16064	883	-1.41021	162	0.04402
410.01	-0.41069	885	-1.09569	163	0.24469
410.03	-0.14409	886.03	-1.35216	164	0.19729
412	-0.1635			167	0.00406
413	-0.2854			169	0.1186
420	-0.26495			171	0.05813
430	-0.10591			172	0.12258
513.02	-0.09811			175	0.17008
520.04	-0.25965			176	-0.00329
540	-0.29064			177	-0.06968
570	-0.05444			180	-0.20462
584	-0.03401			181	0.25648
590.01	-0.09159			186	-0.00171
591.02	-0.14187			187.02	-0.17563
592	-0.39603			188.01	-0.15611
594.02	-0.1097			190.01	0.06469
604.01	-0.2124			194	0.19827
605.05	-0.39689			195.01	-0.18214
617.01	-0.35079			195.02	-0.17443
617.02	-0.24519			196	-0.22391
635	-0.35185			197	0.07808
636	-0.17902			198	-0.01207
637.02	-0.36936			199	-0.21954
638.01	-0.09549			200	-0.21737
638.03	-0.15781			202	0.05132
638.04	-0.39247			203	-0.08807
639	-0.30176			**205**	**0.02471**
640	-0.07522			206	0.05941
641.01	-0.19399			207	-0.13446
643	-0.31836			210	-0.14631
644	-0.04382			211	-0.11346
645	-0.36013			213	0.18336
647.01	-0.30734			215	-0.00623
647.02	-0.38909			217	0.15003
648	-0.16409			218	0.12355
649.01	-0.08132			221	0.20775
649.02	-0.23154			222	-0.09049
650.01	-0.35837			223.01	0.03249
706	-0.26945			223.02	-0.09374
707	-0.03937			224	0.19617

784	-0.29875
825.02	-0.06895
825.04	-0.12423
825.05	-0.10854
826.06	-0.19077
826.11	-0.02211
827.02	-0.13736
861	-0.25583
862	-0.01355
867	-0.39646
868.02	-0.26718
870.01	-0.29966
871.01	-0.30076
874	-0.41292
879.01	-0.2148
879.02	-0.19224
880	-0.32453
881.01	-0.45453
882	-0.43886
883	-0.49867
885	-0.20516

226	-0.01992
228	0.08748
230	-0.09815
231	0.03919
232	0.22595
233	0.0828
234	0.03253
235	-0.1681
236	-0.07208
237	0.01358
238	-0.18528
241	-0.21849
242	-0.03202
243	-0.19725
244	0.10415
245	0.19061
247	-0.04249
249	0.01119
250	-0.20784
251.01	-0.11488
251.02	-0.17825
252	-0.14317
253	0.06585
254	0.15695
256	-0.10532
257	-0.00952
260	-0.21154
261	-0.11858
262	0.00321
263	0.04926
264.01	-0.11777
265	0.02377
267	0.24129
268.01	0.10207
268.02	-0.09182
269	0.06236
270	0.0268
271	-0.05681
272	-0.14703
273	-0.02711
275	0.07978
276	-0.181

277	-0.11633
278	-0.21145
279	0.14072
280	-0.10605
281	-0.0742
283.01	-0.06415
284	0.06347
285	-0.05294
287.02	0.07256
290.01	0.14028
290.02	-0.05733
290.03	-0.20413
290.06	-0.12771
290.08	-0.03913
290.09	-0.08178
291.01	-0.1144
291.02	0.22788
302	-0.15748
306	0.23122
307	-0.13077
308	-0.09535
311	-0.17445
312	-0.11883
313	0.17311
316	0.03063
320	-0.05058
322.02	0.03006
322.04	0.13654
323	0.27055
324.01	-0.03321
324.02	-0.04932
325.01	-0.1942
325.02	-0.13839
326.02	-0.00334
327	-0.20077
328	-0.21609
330	-0.13182
340	0.09606
350	0.14412
361	-0.014
363	0.25007
364	-0.21892

365	0.18098
366	0.13943
367	0.18696
380	0.27037
381	0.02503
382.01	-0.0077
382.02	0.24203
383.01	-0.02144
385	0.04685
391	0.0289
392	0.23694
393	-0.0821
395.02	0.09386
395.03	-0.17303
396	-0.15093
397	-0.12834
410.01	0.05125
410.03	0.12303
412	-0.11329
413	-0.13716
415.03	-0.12868
415.04	-0.18471
416.01	0.17044
416.02	0.04412
418	0.06856
419	-0.02333
420	0.00886
421.02	-0.20212
430	-0.20309
450	0.012
451	-0.01849
452	-0.07999
460	-0.11332
462.01	-0.215
462.02	0.06477
470.01	-0.04894
470.03	-0.05587
470.05	0.17582
511.01	0.00073
511.02	0.184
512.03	-0.16329
513.01	-0.1232

513.02	0.07288
514.02	-0.18608
515.03	-0.16776
520.02	-0.0566
521.01	-0.12868
521.05	-0.10118
521.06	0.10625
521.07	0.16356
522.02	0.01793
523	0.03777
530	-0.21675
550.04	0.07237
585.01	-0.04042
585.02	-0.13976
591.01	-0.12884
591.02	-0.19516
594.01	-0.17117
594.02	-0.09142
600.02	0.25968
601.01	0.08645
602.01	0.25662
603.01	0.10604
603.03	0.00142
604.01	-0.14532
604.02	-0.11514
604.04	0.02803
604.05	-0.1319
605.02	0.22237
605.03	0.03754
605.05	0.08503
610.02	-0.19428
611.01	-0.03964
611.02	-0.05965
613	-0.15293
615	-0.22329
628.01	0.1492
629	-0.0507
630.01	-0.22285
630.02	-0.01767
632.03	0.22667
633	-0.06749
634	-0.17265

636	0.11297
637.01	-0.09872
638.04	-0.18747
639	0.01263
642	0.12894
643	0.1432
645	-0.01521
647.01	-0.06502
647.02	-0.01797
648	-0.04284
649.01	-0.16901
650.02	0.00763
650.03	-0.20957
651.01	-0.17146
651.02	-0.17687
652.04	-0.06199
652.05	-0.16009
652.07	0.22712
660.03	-0.19083
676.03	-0.10625
677.02	-0.11828
684.05	-0.15354
687.01	-0.02643
687.02	-0.14103
687.03	-0.15561
688.02	-0.09958
710.01	-0.05081
725.04	-0.21574
734.02	-0.05613
755.01	-0.19986
775	0.04156
776	-0.10581
800.01	-0.20671
825.01	-0.00092
825.02	-0.17178
825.03	-0.03995
825.05	0.19015
826.02	-0.15214
826.05	-0.04046
826.07	0.088
826.09	0.21022
826.1	0.00187

826.11	-0.14728
826.12	0.0227
827.02	-0.01823
827.03	0.07786
828.02	0.18244
830.01	0.02843
833	-0.04857
851	-0.14103
853.03	-0.19568
853.04	-0.11463
854.01	-0.1237
855.01	-0.0434
857.12	-0.21827
861	-0.00477
863.01	0.24487
873.02	-0.13536
875	0.00605
876.05	0.15252
877.02	-0.07964
878	-0.0839
883	-0.20041
884.01	0.06476
884.02	0.06442
885	0.10314
886.01	-0.08611
886.02	-0.14272
887.05	0.09397
887.06	0.00741
888	-0.071
901.01	0.03132

APPENDIX D: COMPLETE ONE-WAY ANOVA RESULTS FOR CENSUS TRACT PEER GROUPS

Levene Test

Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
Avg. # children	9.539	3	40	.000
Avg. household size	5.758	3	40	.002
Unemployment rate	13.509	3	40	.000
Median after-tax family income	4.810	3	40	.006
Proportion of pop. with non-official MT	7.156	3	40	.001
Proportion of pop. w/Canadian citizenship	10.155	3	40	.000
Dwelling density indicator	4.867	3	40	.006
Proportion of com/res land use	8.162	3	40	.000
Proportion of park-space/res land use	10.616	3	40	.000
Linear distance to CBD	8.441	3	40	.000

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Avg. # children	Between Groups	1.125	3	.375	6.053	.002
	Within Groups	2.479	40	.062		
	Total	3.604	43			
Avg. household size	Between Groups	8.598	3	2.866	67.870	.000
	Within Groups	1.689	40	.042		
	Total	10.287	43			
Unemployment rate	Between Groups	226.074	3	75.358	6.442	.001
	Within Groups	467.954	40	11.699		
	Total	694.028	43			
Median after-tax family income	Between Groups	3.775E9	3	1.258E9	24.198	.000
	Within Groups	2.080E9	40	5.200E7		
	Total	5.855E9	43			
Proportion of pop. with non-official MT	Between Groups	.555	3	.185	21.508	.000
	Within Groups	.344	40	.009		
	Total	.899	43			
Proportion of pop. w/ Canadian citizenship	Between Groups	.088	3	.029	11.515	.000
	Within Groups	.102	40	.003		
	Total	.190	43			

Dwelling density indicator	Between Groups	6.847	3	2.282	455.763	.000
	Within Groups	.200	40	.005		
	Total	7.047	43			
Proportion of com/res land use	Between Groups	.122	3	.041	13.640	.000
	Within Groups	.120	40	.003		
	Total	.242	43			
Proportion of park-space/res land use	Between Groups	.102	3	.034	2.840	.050
	Within Groups	.480	40	.012		
	Total	.583	43			
Linear distance to CBD	Between Groups	1.214E10	3	4.048E9	180.578	.000
	Within Groups	8.967E8	40	2.242E7		
	Total	1.304E10	43			

APPENDIX E: CHARACTERISTICS OF INDIVIDUAL CENSUS TRACTS WITHIN PEER GROUPS

“Ideal” Urban Group (Selected manually)

CT ID	51	65.01	66.02	67	68	78	133	134	135	136	Total
Population	1536	6171	2017	1873	2135	3755	2414	835	1675	2740	25,151
Area (sq. km)	0.22	0.14	0.15	0.18	0.19	0.39	0.15	0.09	0.12	0.18	1.81
Average number of children per household	0.7	0.8	0.8	1.5	2.2	1	0.6	0.5	0.7	0.8	
Average household size	1.7	1.6	1.5	2.3	2.8	1.9	1.6	1.7	1.8	1.9	
Unemployment rate	8.0%	16.0%	12.9%	12.1%	24.7%	5.4%	5.3%	3.9%	4.4%	4.8%	
Median after-tax family income	48,738	20,195	36,945	45,910	26,363	50,894	48,796	54,273	55,390	46,902	
Proportion of population with non-official mother tongue	15.9%	61.8%	38.3%	36.7%	50.5%	38.1%	32.3%	9.6%	21.5%	30.3%	
Proportion of population over age 18 with Canadian citizenship	67.9%	48.9%	74.4%	66.6%	57.9%	73.1%	77.8%	83.8%	72.2%	73.9%	
Proportion of dwellings classified as row-houses, duplexes or apartments	100.0%	99.6%	99.6%	98.8%	99.3%	97.9%	100.0%	100.0%	97.8%	99.7%	
Ratio of commercial land use area to residential land use area	14.3%	34.3%	15.0%	0.1%	0.0%	5.3%	21.5%	14.1%	20.9%	16.4%	
Ratio of park-space land use area to residential land use area	0.0%	0.0%	19.9%	0.0%	17.8%	14.3%	0.4%	33.3%	0.0%	0.0%	
Linear distance to CBD (km)	1.7	1.4	1.8	1.9	1.4	2.2	1.4	1.6	2.0	1.8	

Urban Group (Selected by factor analysis)

CT ID*	10	175	190.01	205	206	235	322.04	323	883	885	Total
Population	1351	1880	3477	2126	2617	1856	3586	3113	2671	3879	26,556
Area (sq. km)	0.93	0.12	0.46	0.18	0.23	0.12	0.45	0.62	0.99	1.61	5.71
Average number of children per household	0.8	0.8	0.8	0.9	0.9	0.8	0.9	0.8	0.8	0.9	
Average household size	2.0	1.8	1.9	1.8	1.9	1.9	2	2	1.8	1.9	
Unemployment rate	6.8%	6.1%	4.7%	3.9%	5.5%	4.4%	4.2%	3.8%	9.7%	7.2%	
Median after-tax family income	52,171	57,677	57,238	57,664	60,020	46,388	62,498	52,490	55,085	57,421	
Proportion of population with non-official mother tongue	6.3%	8.1%	19.7%	6.9%	9.2%	15.6%	27.0%	15.6%	8.1%	8.5%	
Proportion of population over age 18 with Canadian citizenship	82.5%	77.4%	84.1%	81.0%	79.9%	84.1%	85.7%	80.1%	85.3%	81.5%	
Proportion of dwellings classified as row-houses, duplexes or apartments	93.0%	99.0%	96.4%	99.6%	98.6%	97.4%	85.3%	95.2%	80.6%	82.5%	
Ratio of commercial land use area to residential land use area	0.6%	12.1%	1.0%	8.1%	5.3%	4.4%	1.6%	0.4%	1.5%	0.3%	
Ratio of park-space land use area to residential land use area	42.7%	0.0%	17.7%	0.0%	8.5%	0.0%	14.9%	48.1%	4.3%	33.9%	
Linear distance to CBD (km)	8.5	3.8	8.4	5.2	5.6	6.2	9.4	10.4	4.6	7.0	
* CT 827.02 omitted											

Suburban Group (Selected by factor analysis)

CT ID	453.01	462.01	470.01	515.03	522.01	522.02	530	625.02	652.04	659.07	660.03	857.09	858.03	876.04	Total
Population	5131	5140	7213	3437	3725	3804	5948	5990	4244	8370	7241	4187	7775	6171	78,376
Area (sq. km)	1.98	2.37	3.59	0.94	1.24	1.07	2.22	1.97	1.26	2.29	2.43	2.36	12.9	2.26	38.88
Average number of children per household	1.3	1.2	1.3	1.2	1.3	1.2	1.2	1.3	1.2	1.2	1.3	1.3	1.2	1.3	
Average household size	2.8	2.7	2.7	2.9	2.8	2.6	2.8	3	2.8	2.8	2.8	2.9	2.9	2.9	
Unemployment rate	7.2%	4.3%	6.8%	5.3%	3.9%	3.6%	3.8%	4.4%	4.6%	2.8%	3.3%	3.1%	3.8%	4.4%	
Median after-tax family income	70,908	74,800	78,240	64,105	67,787	67,455	66,413	55,095	68,905	63,952	73,247	72,148	63,744	75,553	
Proportion of population with non-official mother tongue	18.2%	17.2%	26.5%	31.3%	32.6%	33.8%	27.2%	20.8%	20.8%	17.9%	29.2%	11.5%	14.6%	8.9%	
Proportion of population over age 18 with Canadian citizenship	72.3%	71.8%	72.9%	73.2%	74.6%	74.0%	72.8%	72.5%	74.1%	68.7%	71.3%	72.0%	74.2%	71.0%	
Proportion of dwellings classified as row-houses, duplexes or apartments	21.2%	23.0%	33.0%	21.3%	15.6%	37.1%	19.9%	20.2%	13.1%	15.3%	29.5%	29.5%	9.1%	15.6%	
Ratio of commercial land use area to residential land use area	0.1%	1.8%	4.4%	6.3%	0.0%	6.2%	2.0%	3.5%	3.4%	1.1%	0.0%	0.0%	0.8%	0.0%	
Ratio of park-space land use area to residential land use area	4.1%	8.6%	8.2%	5.8%	4.1%	9.2%	3.4%	0.8%	17.8%	0.0%	1.3%	0.5%	4.5%	1.3%	
Linear distance to CBD (km)	19.5	23.2	23.4	24.5	21.7	22.0	18.6	18.6	19.3	20.6	18.5	12.8	14.1	10.4	

Exurban Group (Selected by factor analysis)

CT ID	682.05	690	694	732.01	740	756.02	760	791	792	1003	Total
Population	3228	5826	4586	4958	11676	828	5732	6349	4076	6346	53,605
Area (sq. km)	0.77	65.37	34.82	41.38	185.84	10.76	77.85	4.54	30.83	47.06	499.22
Average number of children per household	1.2	1.1	1.2	1.1	1	1.2	1.1	1.1	1.1	1.1	
Average household size	2.9	2.7	2.8	2.8	2.6	2.8	2.7	2.6	2.6	2.7	
Unemployment rate	3.4%	4.1%	3.1%	3.2%	4.4%	4.7%	2.5%	2.6%	5.3%	4.3%	
Median after-tax family income	62,189	50,100	56,480	59,978	53,377	60,313	62,109	59,709	55,312	61,801	
Proportion of population with non-official mother tongue	2.2%	0.9%	1.3%	1.5%	2.2%	3.6%	2.1%	1.1%	2.5%	1.4%	
Proportion of population over age 18 with Canadian citizenship	73.5%	73.3%	72.4%	72.8%	72.7%	75.2%	72.7%	73.7%	76.8%	73.0%	
Proportion of dwellings classified as row-houses, duplexes or apartments	15.0%	7.2%	9.5%	12.5%	3.9%	1.8%	7.8%	30.6%	5.2%	18.1%	
Ratio of commercial land use area to residential land use area	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	
Ratio of park-space land use area to residential land use area	1.4%	8.8%	0.3%	4.2%	7.1%	0.3%	2.3%	4.0%	6.0%	15.3%	
Linear distance to CBD (km)	29.972	48.627	45.11	35.187	56.426	50.251	44.829	50.6215	53.069	53.446	