# LIFE CYCLE COSTING FOR TRANSPORTATION, HOUSING AND MUNICIPAL SERVICE PROVISION: A CASE STUDY IN MONTREAL, CANADA

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## INTRODUCTION

Urban residential energy use and emissions is a topic of particular importance now, as the proportion of urban residents both worldwide and within Canada continues to increase. It is also now recognized that most "urban" development is actually "suburban" (Queens University News Centre, 2013). As a result, large swaths of land are being converted from farmland and forest to clover leaf interchanges, single-storey office parks and large-lot single family homes. What this means is that the way our cities are currently evolving will put more and more of a strain on the earth's resources, as well as our own finite transportation and other infrastructure budgets as we go into the future. Destinations are growing further apart causing more travel by automobile, while energy sources become more expensive to extract and transform.

Many provinces, metropolitan regions and municipalities also have an emissions reduction target. Quebec, for instance, outlined in their 2006-2012 Climate Action Plan targets of 10% below 1990 emissions levels by 2020 (Ministère du Développement durable, de l'Environnement et des Parcs, 2004); an ambitious goal that requires coordinated action on many fronts. Some of this reduction in emissions will come from improvements in vehicle technology and modal shift away from the single occupant vehicle to transit and active travel, but to enable the latter, land use patterns must be conducive to this type of travel. Only in designing neighborhoods and regional links to provide high accessibility with lower relative mobility will it be possible to reduce the volume of traffic.

Previous studies have compared high-and-low density development energy use and emissions (Norman, MacLean, & Kennedy, 2006), the same outputs in different types of municipality along the urban-rural gradient (Andrews, 2008) or average emissions at the broad metropolitan scale (Glaeser & Kahn, 2010), but there remain unanswered questions and methodological improvements which could be brought to the analysis to improve legibility and applicability, notably, with respect to controlling for household type and location at once.

## OBJECTIVE

The objective of this paper is to quantify the energy use and emissions related to the construction and operation of homes and transportation vehicles under a variety of scenarios, in the goal of defining the optimal development type and gaining a better understanding of the differences in sustainability between a few key scenarios. This work will enable urban planning policy recommendations to be made using local data on development types and likely outcomes.

## LITERATURE REVIEW

There have previously been attempts to assess the sustainability of development in a variety of contexts. The Transportation Research Board (2009) has one of the most authoritative assessments of potential reductions in emissions resulting from intensification policy, both at the level of energy use within the home, as well as resultant from reductions in vehicle kilometers traveled, but their report remains highly aggregate in nature, and the assumptions made are based on American figures. Their goal also seems to have been explicitly to determine what might be a safe percentage decrease in GHGs to be reported given a low replacement rate for housing stock and an existing landscape of car dependence. If we wish to understand the difference in energy use and emissions as a *relative* figure, from one type of potential development to another, we do not need to estimate the total emissions for the country, but can instead focus on neighbourhood development alternatives, calculating the difference between a best and other plausible scenarios.

The studies that come closest to the goals and objectives of this paper are Norman, MacLean, & Kennedy (2006), Andrews (2008), and Glaeser & Kahn (2010).

At present, there exist assessments of the energy use and embedded emissions for buildings, with which the Norman et al. paper deals with very thoroughly. A difficulty with their analysis, however is that it makes the assumption that only two types of development are possible; low density suburban and high density urban. This is problematic as neither can be useful in meeting emissions reductions targets: first because the cores of most central cities have limited potential for redevelopment and intensification, and second because most if not all planners and academics already agree that low density development at the outskirts of metropolitan regions is not part of the solution set.

Andrews (2008), in their assessment of energy use and emissions in different neighborhoods did not simply look to two locations at opposite ends of the spectrum, but instead used the transect idea developed by New Urbanists to categorize jurisdictions as being more or less urban (Duany & Talen, 2002). Andrews calculates energy and emissions for these different types of neighborhood. The paper, however, does not account for open space as a potential carbon sink in a fully rational manner, nor does it separate residential from other land use effects. In essence, any land left undeveloped is considered a carbon sink, which creates a bias that reduces the emissions of outlying tracts, their land not yet having been entirely paved over by development radiating outward from an urban core.

There is a strand of literature that looks specifically at quantifying the social costs of development, in the goal of redressing cross-subsidies and making alternatives to sprawl economically competitive in a market economy – see Blais (2010) for a thorough description. Glaeser & Kahn (2010) falls within this strand of investigation. The authors look at development as it currently exists in different cities and suburbs across the country and try to find where *current* patterns seem to be associated with the lowest energy use and emissions. One of their conclusions is that locations where land use regulations are stricter discourage people to establish there, while also being typically sites of lower emissions. From this they posit that strict land use regulations may be counter-productive in that they discourage development in environmentally beneficial locations; i.e. while these places are *greener*, the policies in place have the unfortunate effect of pushing development away.

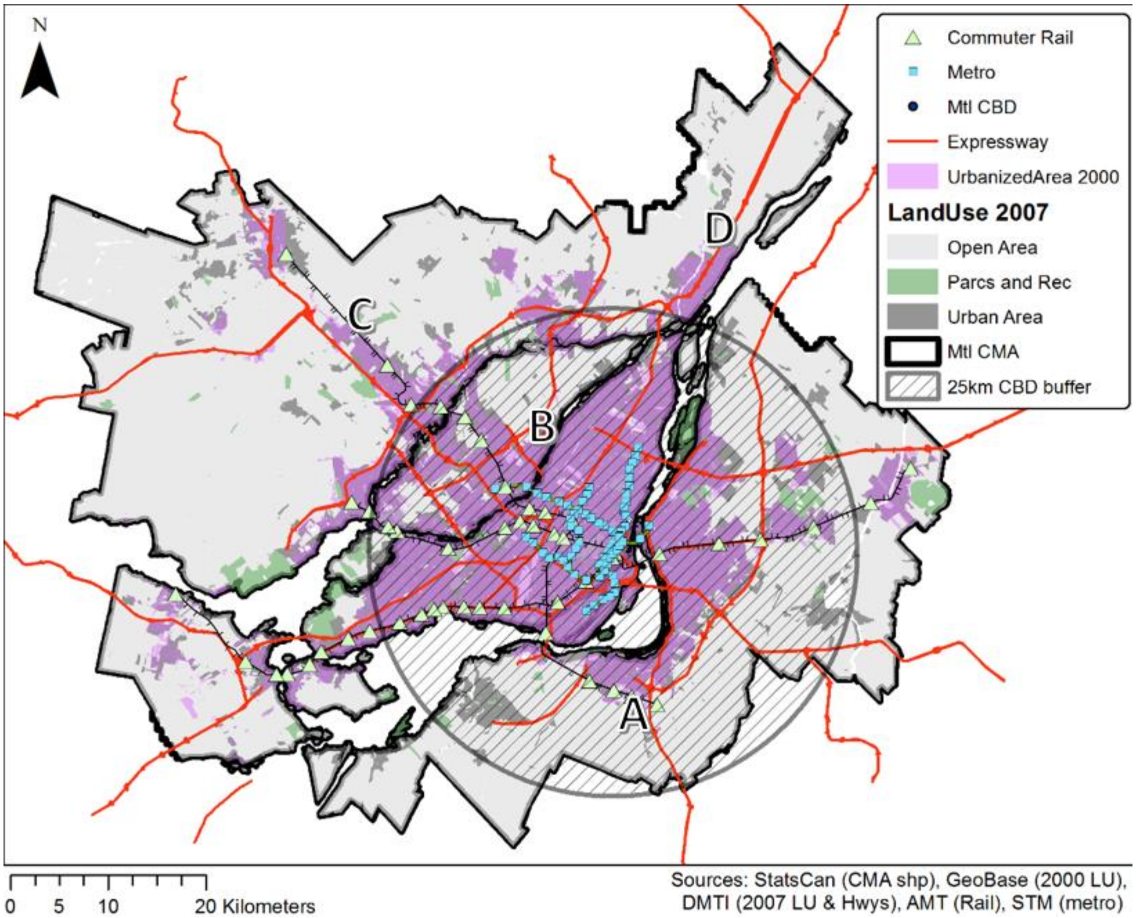
While Glaeser & Kahn’s idea of a carbon tax based on an area’s historic consumption patterns is a conversation starter, there is something to be gleaned from looking at a more meso scale set of observations within an urban area where there are no differences in temperature or energy sourcing. As opposed to assuming that we should move millions of people across the country according to cities’ track records on sustainability, this paper instead seeks to determine the difference between development types within a city and quantify what the best and worst development types would be according to the landscape already present.

## METHOD AND DATA SOURCES

In order to obtain cost and emissions estimates which are not only as realistic as possible, but actually reflect available plots of land in the Montreal metropolitan region, we compared the Plan Métropolitain d’Aménagement et de Développement (development plan for Greater Montreal), or PMAD, map of land to be developed with satellite imagery and land use files obtained from DMTI (DMTI Spatial, 2010) and GeoBase (Natural Resources Canada, 2000). This allowed us to find 4 different sites with key attributes that were available and marked for development in the years to come.

We wished to compare greenfield sites nearer to the core to others further afield, so 15 and 35 km from the CBD were chosen after looking for suitable sites. We also wanted to find sites at each of these distances with and without access to commuter rail stations. While we were able to find a suitable plot of land near an existing commuter rail station 15 km from the CBD (location A, shown on the map below), for a further out location, we chose a plot of land adjacent to existing development along a train line, but at which point there is no existing station (location C). To ensure we were comparing realistic scenarios, in the calculations made for transportation in the scenarios sited near location C, we then added the costs of constructing a rail station along the line and divided by the study period and number of development residents.

**Figure 1 - Location of development sites, transportation infrastructure and land use**




To keep this paper as concise as possible, we present information on only one type of household and one size home. In order to avoid comparing families with children to singles, couples and non-family households in any scenario, and also to control for unit size when looking at embedded and operating costs and emissions, families with children and units of 1,250 square feet were chosen. This made the most sense as all our locations were away from the core in greenfield, typically suburban locations.

In addition, to ensure scenarios had realistic densities for suburban greenfield builds, we looked to the PMAD (Communauté métropolitaine de Montréal, April 2011) and obtained the values of 20, 40 and 70 persons per hectare for future development. When it came to actual neighborhood design types for street layout and space occupied by infrastructure and parks, we looked to design documents published by the CMHC (Canada Mortgage and Housing Corporation, 2002). For development charges, because Montreal "negotiates charges for additional infrastructure work on a case-by-case basis" (Kemp & Tomalty, 2012), we made use of figures drawn from the City of Ottawa reproduced in Blais (2010, p. 93), and adjusted for building and lot footprint. Combining these with land area covered per unit - adapted from Litman (2005) -, emissions per unit of energy from hydro and other sources - taken from version 4.03a of GHGenius (Natural Resources Canada, 2013)-, we were able to calculate estimates of average use of energy under our different development scenarios and for each housing type. The calculations involved combining the average energy use of different housing types and square footage (Statistique Canada, 2011) with the mix of fuel sources for heating and energy. We calculated energy emissions using the mix of energy sources found in Quebec to calculate the cost for electricity spent by each household and looked to the rates charged by Hydro Quebec both in peak and off peak (Hydro Quebec, 2017). This was a simplification to estimate appropriate bills for each type of housing unit. Embedded emissions from housing were calculated using figures obtained from Norman, MacLean, & Kennedy (2006), adjusted to the household types in our scenarios.

To come up with municipal taxes for the different types of neighborhoods, we used a report released by Halifax' regional planning division (Halifax Regional Municipality, 2005) that described the various components included in the mix of services provided by the municipal government (roads, solid waste, libraries, parks, police, fire, etc.), as well as the costs generated by different types of neighbourhood.

The costs associated with vehicle ownership, licensing and maintenance were assumed to be the same on a per vehicle basis (a mid-size sedan was chosen for all households in the CMA) and obtained from CAA's online vehicle cost calculator (Canadian Automobile Association, 2017). With respect to fuel use, the origin-destination survey data (OD) we had access to (Agence Métropolitaine de Transport, 2003-2008-2013) were used to extrapolate yearly vehicle kilometers traveled, in addition to bus and commuter rail trips per household. Scenario averages for kilometers traveled were then associated with the above-chosen sedan, and fuel consumption was calculated. This did not include travel outside the study zone, as such travel would be considered vacation/leisure, and thus assumed still be carried out using the private automobile. For bus and commuter rail trips, fuel consumption data were obtained through an access to information request at both the AMT (Di Lorenzo, 2017) and STL (Côté, 2017), allowing us to come up with per-trip fuel use and emissions rates.

Other calculations were made to determine the neighborhood type and land use properties around specific households included in the OD data by querying the geocoded addresses of survey respondents for population density, land use mix and commuter rail station proximity.

Finally, with regards to transportation costs, transit fare information was obtained from the operators in the region and multiplied by the share of household residents using transit for at least 2 trips on the day of survey (Société de Transport de Montréal, 2013), (Société de Transport de Laval, 2013), (Réseau de Transport de Longueuil, 2013), (Conseil intermunicipal de transport Laurentides, 2013) and (Réseau de transport collectif régional de la MRC de L'Assomption, 2013).

All emissions were converted to dollar figures using the cost of carbon credits obtained from Less.ca (2017) and fuel prices per litre were extracted from (EssenceMontreal, 2017). For adjustments to costs encountered in other sources and reports, we used the Bank of Canada's Inflation Calculator (2017) to convert into 2017 dollars. Analysis results are presented as both personal and social costs to be divided up among residents of a neighborhood. As a result, it is possible to know not only what personal choice would be optimal, but also what the effects would be more broadly of different development types.

## RESULTS

Addressed in the order in which they appear, we can see that development charges obtained in our analysis point to lower costs for residents who choose either to live closer to the city (scenarios 1 through 4) or to live in less land-consumptive types of housing. This naturally results from our method, but what is more interesting are the figures themselves and the potential for presentation of this information to affect prospective home buyers – via eco-label notably. We would also like to indicate once again that housing size was controlled for, and as such the units proposed are all 1,250 square feet. Scenarios 5 and 7, of note, have development charges of nearly $20,000 per unit, while for most other developments, whether one chooses to live in a single family home or not, charges are nearer $10-12,000 and even as low as $4,075 for apartments. The apartments modeled here are not 20 storey towers, but rather context-appropriate buildings of 5 storeys.

| Distance from CBD | 15 km | | | | 35 km | | | |
|---|---|---|---|---|---|---|---|---|
| Scenarios ID | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Locations | A) Along Candiac line, next to train, near highway | | B) Intersection of the 25 and 440, on Île-Jésus | | C) Between Blainville and St-Jerome, with new station | | D) South of L'Assomption | |
| Type of land | Open land | Open land | Brush | Brush | Farmland | Farmland | Farmland | Farmland |
| Approx. gross dens. (units/ha) | 40 | 70 | 40 | 70 | 20 | 40 | 20 | 40 |
| Households | 4080 | 6792 | 4080 | 7132 | 2211 | 4080 | 2392 | 3725 |
| Transport infrastructure | Rail | Rail | Highway | Highway | Rail | Rail | Highway | Highway |
| Land Use | Mixed | Mixed | Residential | Residential | Mixed (adjacent) | Mixed | Residential | Residential |
| Streets | 27 ha | 35 ha | 27 ha | 35 ha | 27 ha | 27 ha | 24 ha | 24 ha |
| Open areas/Parks | 9 ha | 5 ha | 9 ha | 5 ha | 9 ha | 9 ha | 8 ha | 8 ha |
| Residential | 64 ha | 60 ha | 64 ha | 60 ha | 64 ha | 64 ha | 69 ha | 69 ha |
| Housing type | Row and single family homes | Row houses and apts | Row and single family homes | Row houses and apts | Large lot single family homes | Row and single family homes | Large lot single family homes | Row and single family homes |
| Apartments | 0 | 3,924 | 0 | 4,485 | 0 | 0 | 0 | 0 |
| Row houses | 1,169 | 2,867 | 1,169 | 2,647 | 0 | 1,169 | 0 | 2,529 |
| Single family homes | 2,911 | 0 | 2,911 | 0 | 2,211 | 2,911 | 2,392 | 1,196 |
| Development charge/apartment | | $4,075 | | $4,075 | | | | |
| "" /row house | $9,772 | $10,359 | $9,772 | $10,359 | | $9,457 | | $8,742 |
| "" /single family home | $11,775 | | $11,775 | | $19,998 | $11,394 | $18,487 | $18,487 |
| Total dev. charge revenue | $45,696,000 | $45,696,000 | $45,696,000 | $45,696,000 | $44,220,000 | $44,220,000 | $44,220,000 | $44,220,000 |
| Municipal tax/apartment | | $1,049 /yr | | $1,102 /yr | | | | |
| "" /row house | $2,316 /yr | $2,667 /yr | $2,316 /yr | $2,800 /yr | | $2,043 /yr | | $1,724 /yr |
| "" / single family home | $2,791 /yr | | $2,791 /yr | | $4,235 /yr | $2,461 /yr | $4,235 /yr | $3,646 /yr |
| Neighborhood tax revenue | $10,829,765.41 | $11,764,673 /yr | $10,829,765 /yr | $12,353,703 /yr | $9,364,540 /yr | $9,552,153 /yr | $10,130,195 /yr | $8,722,208 /yr |
| Construction emissions/apartment | | 1,057 kg/yr | | 1,057 kg/yr | | | | |
| "" /row house | 958 kg/yr | 958 kg/yr | 958 kg/yr | 958 kg/yr | | 958 kg/yr | | 958 kg/yr |
| ""/single family home | 859 kg/yr | | 859 kg/yr | | 859 kg/yr | 859 kg/yr | 859 kg/yr | 859 kg/yr |
| Electricity cost/apartment | | $927 /yr | | $927 /yr | | | | |
| "" /row house | $1,646 /yr | $1,646 /yr | $1,646 /yr | $1,646 /yr | | $1,646 /yr | | $1,646 /yr |
| "" /single family home | $2,624 /yr | | $2,624 /yr | | $2,624 /yr | $2,624 /yr | $2,624 /yr | $2,624 /yr |
| Electricity emissions/apartment | | 1,274 kg/yr | | 1,274 kg/yr | | | | |
| "" /row house unit | 1,997 kg/yr | 1,997 kg/yr | 1,997 kg/yr | 1,997 kg/yr | | 1,997 kg/yr | | 1,997 kg/yr |
| "" /single family home | 2,982 kg/yr | | 2,982 kg/yr | | 2,982 kg/yr | 2,982 kg/yr | 2,982 kg/yr | 0 kg/yr |
| Vehicles per household | 1.48 | 1.27 | 1.62 | 1.31 | 1.81 | 1.71 | 1.88 | 1.76 |
| Vehicles fixed costs | $12,773 /yr | $11,019 /yr | $14,005 /yr | $11,307 /yr | $15,695 /yr | $14,830 /yr | $16,295 /yr | $15,194 /yr |
| Veh. amortized fixed emissions | 869 kg/yr | 750 kg/yr | 953 kg/yr | 769 kg/yr | 1,068 kg/yr | 1,009 kg/yr | 1,109 kg/yr | 1,034 kg/yr |
| Vehicles operating emissions | 2,121 kg/yr | 1,675 kg/yr | 2,574 kg/yr | 2,073 kg/yr | 3,607 kg/yr | 2,904 kg/yr | 4,168 kg/yr | 3,752 kg/yr |
| Fuel costs | $1,125 /yr | $889 /yr | $1,365 /yr | $1,099 /yr | $1,913 /yr | $1,540 /yr | $2,211 /yr | $1,990 /yr |
| Transit passes | $901 /yr | $1,141 /yr | $835 /yr | $1,197 /yr | $631 /yr | $271 /yr | $382 /yr | $679 /yr |
| Amortized rail station build | | | | | $181 /yr | $98 /yr | | |
| Yr Housing & Transport Costs, Apt | | $15,025 /yr | | $15,632 /yr | | | | |
| "", Row House | $18,762 /yr | $17,362 /yr | $20,167 /yr | $18,050 /yr | | $20,330 /yr | | $21,233 /yr |
| "", Single family home | $20,215 /yr | | $21,619 /yr | | $25,099 /yr | $21,727 /yr | $25,747 /yr | $24,133 /yr |
| Yearly Housing & Transport CO2, Apt | | 3,699 kg/yr | | 4,116 kg/yr | | | | |
| "", Row House | 4,988 kg/yr | 4,422 kg/yr | 5,524 kg/yr | 4,840 kg/yr | | 5,910 kg/yr | | 6,783 kg/yr |
| "", Single family home | 5,972 kg/yr | | 6,508 kg/yr | | 7,656 kg/yr | 6,894 kg/yr | 8,259 kg/yr | 4,785 kg/yr |
| Lifetime Costs per HH, Apt | | $761,259 | | $792,147 | | | | |
| "", Row House | $955,293 | $885,171 | $1,026,202 | $920,109 | | $1,034,529 | | $1,080,066 |
| "", Single family home | $1,031,048 | | $1,101,957 | | $1,285,582 | $1,107,419 | $1,317,231 | $1,232,214 |
| Lifetime Emissions per HH, Apt | | 237,779 kg | | 258,631 kg | | | | |
| "", Row House | 297,292 kg | 269,027 kg | 324,103 kg | 289,880 kg | | 343,417 kg | | 387,044 kg |
| "", Single family home | 341,566 kg | | 368,378 kg | | 425,764 kg | 387,692 kg | 455,894 kg | 282,241 kg |
| Av. Lifetime Emissions per HH | 328,879 kg | 250,972 kg | 355,691 kg | 270,229 kg | 425,764 kg | 375,005 kg | 455,894 kg | 353,397 kg |
| Av. Lifetime Costs per HH | $1,009,340 | $813,573 | $1,080,250 | $839,638 | $1,285,582 | $1,086,532 | $1,317,231 | $1,128,913 |
| *Carbon credit cost (lifetime)* | *$8,222* | *$6,274* | *$8,892* | *$6,756* | *$10,644* | *$9,375* | *$11,397* | *$8,835* |

Table 1 - Transportation and housing life cycle costs and emissions, 50 year timeline and $25 tonne CO2 assumed

Next, looking at the taxes paid by residents, we see that when residents are asked to pay according to the services received, as opposed to a flat rate per unit, significant differences are observed. The differences in electricity costs per year are also significant, a further incentive to choose the more land efficient of alternatives.

Looking to the average transportation costs associated with each scenario, we see that more central households, as well as those near commuter rail stations, own less cars (1.27 to 1.88 cars per HH), as well as consume less fuel ($889 to $2,211 per HH). As transportation makes up the majority of the housing and transportation costs we are looking at (since we do not include mortgages or rent), the difference between a dense, transit-adjacent unit near a higher mix of activities, and a low density, residential-only development near a highway is significant. This is controlling for the extra cost of purchasing transit passes and, as with everything else, is only calculated for families with children. Even when the costs of building a rail station along the St-Jérôme train line are included, residents in scenarios 5 and 6 that are near transit have total transportation and housing costs inferior to those of equidistant developments (scenarios 7 and 8).

In the rows labeled 'Lifetime…', we see the cumulative costs and emissions from housing (municipal taxes, heating and embedded emissions) and transportation (vehicle ownership and maintenance, licensing, fuel use, and transit passes). Over 50 years, controlling for household composition and unit size, Scenario 7 (single family home away from transit) ends up being 73% more expensive ($556K more in 2017 $) than Scenario 2 (apartment near commuter rail). Choosing a single family home near transit and closer to the central city would save $286 K over the same time period.

With respect to emissions, the differences are even starker: the most pollutant-intensive scenario generates more than twice the $CO_2$ of the least (scenarios 2 and 8). These differences, as significant as they may seem, do not greatly affect the costs associated to each development type however. Using the lower-bound figure for carbon credits offered on Less.ca ($25/tonne), this only amounts to a difference of $5,123 over 50 years (in 2017 dollars).

## DISCUSSION AND CONCLUSION

In conclusion, if the provincial government is serious about meeting its emissions reduction targets, this report presents one possible avenue toward reducing the excessive consumption of land and generation of emissions: putting in place policy requiring developers to have their master plans evaluated, and obliging them to provide clear information to consumers on the immediate and long term consequences of their home-buying purchases. Vehicle MPG figures are released to the public, so why not make something similar available for home purchases?

One point to highlight is the negligible impact of the emissions portion when added to the total sum of expenses for households. While part of this is a result of Quebec's high reliance on low-emission hydro-electric power, this also points to the potential for carbon taxes to be internalized without causing chaos. It also highlights that our estimates are rather conservative as i) all vehicle emissions and costs are calculated based on a mid-size sedan and ii) that travel outside the survey area is not counted - rather, households within which individuals made long distance trips outside the study area were removed. Were the work to be reproduced with fuel consumption rates that more accurately reflect the vehicle fleet composition of the suburbs, differences between scenarios would be much greater.

Regarding the question of carbon sequestration or potential for afforestation, the fact that none of the selected sites was currently a forest, but rather open area, farmland and brush, meant the difference between scenarios would be negligible. While research indicates that afforestation on Canadian soil could lead to interesting cumulative sequestration amounts - 172 tonnes per hectare over a 44 year lifespan (Bird & Boysen, 2007)-, significant differences would only exist if the plots were to not be built up and were instead to be the site of an afforestation program. As this was not one of the scenarios, presenting this information in the results table would have been misleading.

**Shortcomings and/or clarifications**

Because we used data from 2003 to 2013 to estimate transportation emissions over 50 years, transit ridership, vehicle ownership and emissions are static. Other than mode shares, changes that could occur would be improvements in the efficiency of homes and cars, which would have some effect on the expenditure for heating and fuel. With respect to the household heating side however, it must be kept in mind that homes have over the last 50 years increased dramatically in size, all the while housing fewer and fewer people (Blais, 2010). The figures we used for heating and energy use per building type are averages, so if the trend continues, it may be that further increases in home size and decreases in persons per household would counter-act the increases in building envelope efficiency – heating being a significant portion of the total home energy use as a result of Montreal's cold climate.

With respect to vehicle emissions, a trend for households is that SUVs and light duty trucks have steadily increased in popularity, causing an increase in emissions in the transportation sector (Ministère du Développement durable, de l'Environnement et des Parcs, 2004). As a result, figures estimated with smaller, lighter vehicles counteracts the effect of increases in efficiency. Regarding the costs disbursed by households for purchasing, maintaining and refuelling their cars, we chose to use the average costs of a mid-size sedan for all households in our sample, a choice which again makes for very conservative estimates of fuel and vehicle purchases.

As for municipal tax and development charges for infill or densification, there would be potential for using these funds to give money back to the community already in place, in turn reducing friction between existing residents and developers, and offsetting issues of NIMBY'ism. Such a measure would encourage densification and show existing residents the benefits of smart growth.

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