INDIVIDUAL EXPOSURE TO TRAFFIC RELATED AIR POLLUTION ACROSS LAND-USE CLUSTERS

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ABSTRACT

In this study, we estimated the transportation-related emissions of nitrogen oxides (NO_x) at an individual level for a sample of the Montreal population. Using linear regression, we quantified the associations between NO_x emissions and selected individual attributes. We then investigated the relationship between individual emissions of NO_x and exposure to nitrogen dioxide (NO_2) concentrations derived from a land-use regression model. Factor analysis and clustering of land-uses were used to test the relationships between emissions and exposures in different Montreal areas. We observed that the emissions generated per individual are positively associated with vehicle ownership, gender, and employment status. We also noted that individuals who live in the suburbs or in peripheral areas generate higher emissions of NO_x but are exposed to lower NO_2 concentrations at home and throughout their daily activities. Finally, we observed that for most individuals, NO_2 exposures based on daily activity locations were often slightly more elevated than NO_2 concentrations at the home location. We estimated that between 20% and 45% of individuals experience a daily exposure that is largely different from the concentration at their home location. Our findings are relevant to the evaluation of equity in the generation of transport emissions and exposure to traffic-related air pollution. We also shed light on the effect of accounting for daily activities when estimating air pollution exposure.

Keywords: transport emissions, traffic related air pollution, exposure, land-use, built environment, travel survey

1. INTRODUCTION

Transport plays a crucial role in urban development by providing access to education, markets, employment, recreation, health care and other key services. Currently, 82% of Canadian commuters drive to work while the remainder rely on public transit and active transportation (Turcotte, 2011). In Canada, on-road traffic accounts for 19% of nitrogen oxide (NO_x) emissions and in Montreal, Canada's second largest city, transportation accounts for 85% of NO_x emissions (Brisset and Moorman, 2009; Statistics Canada, 2012). In urban areas, NO_x often refers to NO and NO_2 since the contribution of other nitrogen oxides is minimal. NO_x concentrations are often used as a tracer of road traffic emissions (Lewne et al., 2004). NO_x is always higher in the vicinity of roadways and lower further away, as roads are the major source of NO_x emissions. Meteorological parameters such as wind speed and direction affect the decay of NO_x concentrations away from the roadway. Ambient nitrogen dioxide (NO_2) is associated with vehicular traffic since vehicles mostly emit NO, which is then transformed to NO_2 through photochemical reactions involving ozone and volatile organic compounds. However, because ambient NO_2 is also affected by other sources (such as industries), we would expect NO_2 to have lower spatial variability compared to NO_x concentrations that would exhibit large differences between roadways and residential areas. Gilbert et al. (2005) argue that more than 50% of the variability in air pollution concentrations in Montreal can be explained by local traffic.

Exposure to traffic-related air pollution has been associated with various acute and chronic health effects (Cesaroni et al., 2012; Crouse et al., 2010; Gan et al., 2012; Künzli et al., 2000; Smargiassi et al., 2005). A number of studies have established positive associations between various cancers and exposure to NO_2 an accepted marker of traffic-related air pollution (Ahrens, 2003; Costa et al., 2014; Crouse et al., 2010; Parent et al., 2013; Snowden et al., 2014; Shekarrizfard et al., 2015). Part of the challenge of reducing ambient air pollution in urban areas involves reducing the demand for private motorized transportation at an individual and household level. As such, there is a need for analysis tools that can assist policy-makers in evaluating the impacts of transport policies on urban air quality and population exposure. Tools that can provide detailed air emission estimates at a person and trip level are also of extreme relevance to the appraisal of transport plans. Recently, a number of researchers developed modelling frameworks that account for vehicle emissions whereby activity-based models were used to calculate person- and trip-level emissions (Beckx et al., 2009a). A number of studies have also included an analysis of atmospheric dispersion and population exposure (Beckx et al., 2009b; Hatzopoulou and Miller, 2010; Int Panis et al., 2011).

Travel activity, land use patterns, and the distribution of traffic often lead to inequities in the exposure to vehicle-related air pollutants (Buzzelli and Jerrett, 2003, 2007; Houston et al., 2004; Jerrett, 2009). Individuals who live in densely populated areas may be exposed to higher concentrations while generating low levels of emissions throughout their daily travel (Dannenberg et al., 2003). Most studies that examine the generation of transport-related emissions ignore their effect on air quality and exposure, while studies that investigate exposure to air pollution rarely investigate the generation of air emissions (Fallon, 2002; Hatzopoulou and Miller, 2010; Havard et al., 2009; Sider et al., 2013).

In this paper we quantify the emissions of -and exposure to- traffic-related air pollution simultaneously at an individual level. We hypothesize that high emitters would reside in areas characterized by low air pollution (e.g. suburbs) while low emitters would reside in areas with poor air quality (neighborhoods of the inner city). We also investigate the relationship between both variables across different land-uses and socio-economic characteristics.

2. MATERIALS AND METHODS

Our methodology consists of three main steps: 1) generating individual-level NO_x emissions from daily travel using a traffic assignment model extended with detailed emission modelling capability, 2) estimating individual daily exposure to NO_2 using a land-use regression model; and 3) investigating the determinants of NO_x emissions and the relationship with NO_2 exposures as a function of land-use and socio-demographic characteristics. Our study area is focused on the Island of Montreal (Fig. 1).

2.1 Description of Data Sources

We estimated NO_x emissions for car users using a transportation and emissions model. This model includes a traffic assignment component linked with an emission tool that simulates traffic flows and emissions for driving trips in the Montreal metropolitan region (Sider et al., 2013). The traffic assignment model, which is developed in the PTV VISUM platform (Vision, 2009), simulates traffic flow, average speed, and vehicle mix on every road segment and was validated against traffic counts at several major intersections and bridges within the region ($R^2 = 0.65$) (Sider et al., 2013). Based on the vehicle mix per road segment, average speed, and type of roadway (e.g. highway vs. arterial road with intersections), an emission factor for NO_x was assigned to the road segment. Emission Factors were derived from the MOtor Vehicle Emission Simulator (MOVES) model, with input data describing local conditions (USEPA, 2013). After summarizing the daily driving trips for each person in the origin-destination survey, NO_x emissions were calculated for each individual.

In addition to deriving individual NO_x emissions from driving, we made use of estimates of NO_2 concentrations from a LUR model (Crouse et al., 2009), to generate a NO_2 polygon-based map (with gridcell dimensions 80m x 80m amounting to a total of approximately 60,000 polygons). This map (Fig. 2) was used to identify the NO_2 concentration at the home location of every individual as well as estimate daily exposures using data on activity locations using ESRI's ArcGIS. Since the NO_2 estimates were derived from three separate 2-week sampling periods in 2006 thus representing a long-term average; we recognize that what we consider a daily exposure is a weighted average NO_2 concentration across daily activity locations (including home). Therefore the spatial variability in NO_2 concentrations is accounted for in the exposure metric but not the temporal variability. Our activity-weighted NO_2 concentration (in ppb) per person was estimated using Equation (1).

$$C^{i}_{a-NO_2} = \sum_{k=1}^{m} \frac{C^{k}_{NO_2} \times t^{k}_{stop}}{24} \tag{1}$$

In Equation (1), m is number of trips for each individual (i), $C^{k}_{NO_2}$ is the NO_2 concentration (in ppb) assigned to a destination using the NO_2 polygon map, and t^{k}_{stop} is the total time an individual spent at every destination (in hours). We define the stop time (t^{k}_{stop}) at each destination as the difference between the start time of the trip *leaving* the activity location and the start time of the trip *leading* to the activity. This means that the time spent on the trip leading to an activity contributes to the exposure during that activity. We make this assumption to avoid calculating exposures during travel. While we recognize this step as an approximation, it is made due to the lack of information on in-vehicle exposures across modes.

While NO_x emissions were generated for drivers only, daily NO_2 exposures were compiled for drivers and transit riders but not for those who took active transportation. This simplification is due to the fact that we could not infer activity times associated with walking and cycling trips due to the lack of paths and travel times for these trips. Future model developments will address path selection and travel times for active transport users. We made use of the 2008 Origin-Destination (O-D) survey for Montreal (AMT, 2010) to extract individual daily trip characteristics including origin and destination coordinates, trip start time, mode and purpose, as well as individual and household attributes (age, gender, employment status, household size, residential location, and vehicle ownership). The OD survey includes information on a 5% sample of the Montreal population, encompassing a total of 355,000 daily trips conducted by approximately 157,000 individuals associated with 66,000 households across the metropolitan region. We restricted the data to the Island of Montreal (Fig. 1). Also, we considered only single mode trips, thus yielding a final dataset of approximately 32,000 individuals. The latter restriction was needed in order to facilitate the inference of trip paths and travel times across the road network.

Emissions and exposures were evaluated in the context of the residential location of individuals in Montreal. For this purpose, we used factor analysis and clustering methods to develop “land-use clusters” based on the 1,552 Traffic Analysis Zones (TAZs) in Montreal. The geographic unit of analysis is the Traffic Analysis Zone (TAZ), a division used by the Québec Ministry of Transportation (MTQ) in travel demand modelling and traffic assignment. A host of variables were compiled at the TAZ level including: land-use variables (such as residential density, commercial density, and governmental and institutional density), transportation network characteristics (such as length of highways, minor roads, and major roads), public transit (bus stops and metro stations), socio-economics (such as population density, job density, and average/median income) and point of interests (such as restaurants, bars, and other commercial enterprises). All of the variables mentioned were extracted from the Transportation Research at McGill (TRAM) database: for the land use, point of interests and streets network, the DMTI Spatial Inc. Database 2009 was used, defining the road and land-use categories; the bus and metro stops are derived from the local transit provider (STM 2010), the socio-economic data from Statistics Canada.

Due to the presence of a large number of variables that might be correlated with each other, factor analysis was used to retrieve a smaller number of principal components. Then, a two-step cluster analysis was used to classify each zone to be part of a cluster based on original variables and derived components. Several possible loading configurations of variables for factor and cluster analysis were used. Principal components estimation and varimax rotation were used in deriving the results of factor analysis. Factor loadings below 0.20 were considered insignificant. Three separate factors were identified for: 1) Public transport attributes 2) Road network attributes and 3) Points of interest attributes. Public transport attributes of a TAZ yielded two components representing metro and bus service. The road network component captures transportation network characteristics including the density of highways, major roads and local streets. The points of interest factor encompasses the density of restaurants, bars and other commercial enterprises in a zone.

2.2 Statistical Analysis

Our investigation addressed three different dimensions to the question of emission generation and exposure at the individual level. First, we regressed the total NO_x emissions generated by drivers as a function of socio-economic variables. Second, we contrasted individual NO_x emissions and NO_2 concentrations at the home location for these same individuals in order to investigate whether "high emitters" resided in relatively low polluted areas. Finally, we examined whether average NO_2 concentrations at home locations were sufficient to understand daily exposures by contrasting NO_2 at home with daily activity-weighted NO_2 exposures.

In order to identify the main variables associated with NO_x emissions, we used a log-linear multiple regression model to relate the logarithm of the generated emissions for drivers with individual characteristics including employment status, gender, age, vehicle ownership, vehicle type and age. We used an iterative process that allows dropping or adding variables. For this purpose, we eliminated from the model the predictors one-by-one on the basis of their statistical significance. The performance of the regression was evaluated using the root mean square error (RMSE) and R^2 of regression.

In order to compare daily NO_x emissions from travel with NO_2 concentrations at home locations of the same individuals, we divided car users into four groups based on their home location within one of the four land-use clusters that we identified in the cluster analysis. We conducted a descriptive analysis to identify the clusters in terms of their contribution to traffic emissions and air quality. In addition, we developed an exposure-emission index, which helped us visualize the agreement between emissions and exposure (Equation 2). For example, this index would represent whether those who emit a lot are also exposed to poor air quality at their home location or whether they enjoy low concentrations of NO_2 at home. For this purpose, we converted NO_x emissions and NO_2 concentrations into deciles (with 1 indicating the lowest decile and 10 the highest) and computed the ratio of NO_2 to NO_x (in deciles) at each TAZ. The ratio ranges from 0.1 representing minimum NO_2 exposure and maximum NO_x emissions to 10 representing maximum NO_2 exposure and minimum emissions (Equation 2).

$$\textit{Exposure to emission index} = \frac{NO_2 \text{ exposure decile}}{NO_x \text{ emission decile}} \qquad (2)$$

Finally, we conducted a comparison between daily activity-weighted NO_2 exposure and average NO_2 concentration at the home location to evaluate the size of the discrepancy between both measures. Traditional epidemiologic studies often rely on the air pollution concentration at the home location as a potential predictor for the odds of various air pollution-related health effects (Hamra et al., 2015; Lee et al., 2014; Parent et al., 2013; Chen et al., 2008; Krämer at al., 2000). This dimension of our analysis investigates whether daily exposure can be approximated by the daily average concentration at home. We conducted this analysis for both drivers and transit riders. Moreover, we examined the frequencies of individuals for whom the differences between the activity-weighted and at-home exposures are 'large' (i.e. those who accumulate in a day a lot more or a lot less than the concentration at home). Our threshold for a 'large' difference is a difference between an activity-weighted concentration and concentration at the home location that is 20 percent higher or lower than the mean difference for all individuals. The frequency of individuals (*f*) with a 'large' difference is identified using Equations (3) and (4). We conducted this analysis by land-use cluster and for car (*j=1*) and transit users (*j=2*) separately:

$$f_j = 1 - \frac{\sum_{i=1}^{N} 1_{[C_{\min}, C_{\max}]}(C_{a-NO_2}^{i})}{N} \quad \text{j=1, 2} \tag{3}$$

$$1_{[C_{\min}, C_{\max}]}(C_{a-NO_2}^{i}) = \begin{cases} 1 & C_{h-NO_2} - \alpha \overline{C}_{h-NO_2} < C_{a-NO_2}^{i} < C_{h-NO_2} + \alpha \overline{C}_{h-NO_2} \\ 0 & \textit{otherwise} \end{cases} \tag{4}$$

In Equation (3), N is the number of individuals in each cluster, $C_{a-NO_2}^{i}$ (in ppb) represents the activity-weighted NO_2 exposure and $1_{[C_{\min}, C_{\max}]}(C_{a-NO_2}^{i})$ is an indicator function of the home-NO_2 exposure (C_{h-NO_2}) which is defined in Equation (4) and based on (Ganji, 2010). In Equation (4), α is equal to 0.2 (indicating our threshold of 20%) and $\overline{C}_{h-NO_2}$ represents the mean at-home concentration for all individuals in a given cluster.

3. RESULTS AND DISCUSSION

3.1 Land-Use Clusters

The Montreal region consists of 1552 Traffic Analysis Zones (TAZs). We used factor analysis and clustering methods to identify four different clusters.

Based on the original variables and the three components: Public Transport attributes, Road Network attributes and Point of Interest attributes, a two-step cluster analysis was employed to classify TAZs into four distinct clusters. A cluster analysis maximizes differences amongst clusters and minimizes the variation within each cluster. Further, a descriptive analysis was used to examine the zonal characteristics of each cluster. Overall, the factor analysis and cluster analysis provided intuitive and reasonable results. Table 1 shows the final results of factor analysis (in the first part of the table) and cluster analysis and the mean value of zonal attributes for each cluster (in the second part of the table). Principal components estimation and varimax rotation were used in deriving the results of factor analysis. Factor loadings below 0.20 were considered insignificant and were not presented in the table.

Cluster 1 indicates zones with higher population density, higher governmental and institutional areas, denser road network and better access to metro and bus service. It characterizes most of the downtown. Cluster 2 characterizes zones with higher industrial density and lower residential, governmental and institutional densities and poorer transit accessibility. Cluster 3 includes zones with higher residential density and lower industrial density. Zones with fewer points of interest, lower population density and lower accessibility to transit service were included in cluster 4. Clusters 3 and 4 refer to the zones located along the periphery of the region and away from the central and dense areas (Fig. 3).

3.2 Regression of NO_x Emissions against Individual Attributes

Fig. 4 illustrates the descriptive statistics and frequency distribution of NO_x emissions at the individual level for all drivers. The results of a log-linear multivariable regression analysis are presented in Table 2. We observe that the emissions generated per individual are positively associated with gender (males generating more than females), vehicle age and type (older and larger vehicles emitting higher levels), as well as employment status. We observe that passenger trucks (e.g. sports utility vehicles) with model years older than 2000 were associated with higher emissions.

Average NO_x emissions were calculated for the four land-use clusters based on the individuals residing in each cluster (Table 3). We observe that the mean NO_x varies in different clusters and is higher for clusters 3 and 4. This indicates that individuals living along the periphery and away from the central and dense areas generate higher NO_x emissions from travel.

3.3 Comparison of Individual NO_x Emissions and NO_2 Concentrations at Home

Individual NO_x emissions generated in section 3.2 were compared with NO_2 concentrations at the home locations of the same individuals. Table 4 presents mean NO_x emissions per individual and mean NO_2 concentrations per land-use cluster. We observe that while mean NO_x emissions increase from cluster 1 to cluster 4 indicating that central neighborhoods generate lower emissions per person, NO_2 concentrations are lowest in cluster 4 and highest in cluster 1. This means that individuals who generate higher NO_x emissions from travel tend to reside in neighborhoods with lower NO_2 concentrations, while individuals associated with low levels of NO_x emissions from travel, reside in clusters with high concentrations of NO_2. Note that while the differences in mean NO_x emissions and mean NO_2 concentrations across clusters are small, they are nonetheless significant.

Fig. 5 illustrates the spatial distribution of the exposure to emission index (Equation 2) at a TAZ level. We observe that for cluster 4 (as presented in Fig. 3), which characterizes peripheral areas, our proposed index is lowest indicating that the NO_x decile is much higher than the NO_2 decile therefore characterizing these areas as “high emitters, low exposure”. In contrast, areas highlighted in red in Fig. 3, and which correspond to many of the neighborhoods in clusters 1 and 2, experience “high exposure and low emissions”.

3.4 Comparison between Daily Activity-Weighted NO_2 Exposure and NO_2 at Home

Recall that due to the difficulty in computing commute-level exposures, we approximated daily exposures with activity-weighted NO_2 concentrations (Equation 1). In this exercise, NO_2 concentrations were computed for drivers and transit riders. The descriptive statistics for activity-weighted and at-home NO_2 exposures are presented in Table 5. It is clear that clusters 1 and 4 have the highest and lowest NO_2 exposures (daily and home), respectively. We also observe that in clusters 1 and 2 with the highest NO_2 concentrations, the activity-weighted exposures are lower than at-home concentrations indicating that most individuals tend to accumulate a daily concentration slightly lower that the concentration at their home location. In contrast, in clusters 3 and 4, characterized by lower NO_2 concentrations, individuals tend to accumulate a slightly higher concentration throughout the day. Obviously, they are more likely to be present in more polluted neighbourhoods if they live in areas with lower concentrations. While these differences are small, they are nonetheless significant (Fig. 6).

Fig. 7 illustrates the frequency distributions of the differences between activity-weighted and at home NO_2 concentrations computed at an individual level ($NO_{2\ activity\ weighted}$ - $NO_{2\ home}$). As expected, we observe that positive differences occur more frequently in clusters 3 and 4. This means that individuals residing in these clusters worsen their daily exposure by leaving home while individuals residing in clusters 1 and 2 improve their daily exposure by leaving their home. Fig. 7 also shows the percentage of individuals with ‘large’ differences between activity-weighted and at-home concentrations (as formulated in Equation 3) for car (f_1) and transit (f_2) users separately. These values illustrate the percentage of car and transit users who experienced a level of exposure that is largely different from the mean in a specific cluster (smaller than C_{min} which represents the mean minus 20% or larger than C_{max} which represents the mean plus 20%). In general, we observe that approximately between 20% and 45% of individuals experience a ‘large’ change in exposure (in either direction) when accounting for their activities compared to the concentration at the home location. Most noticeably in clusters 1 and 3, we observe that more drivers decrease their exposure by leaving their home compared to transit riders. This can be seen when examining percentages of drivers and transit riders in clusters 1 and 3 with exposures lower than C_{min}. This observation is coherent with our intuitive hypothesis that drivers travel longer distances away from their home and therefore increase their chances of visiting locations with concentrations that are lower than the concentration at home. Transit riders are more likely to stay closer to home.

4. CONCLUSION

In this study, we quantified the effects of the built-environment and individual attributes on the generation of, and exposure to, traffic emissions. Our results show that transport emissions are associated with gender, employment status, age, vehicle type and model year. We also observe that the “highest emitters” reside in the peripheral areas with limited accessibility to retail and employment opportunities. They also experience the lowest air pollution concentrations at their home location. In contrast, individuals who reside in areas with the highest concentrations, generate the least amount of emissions during daily travel.

While these findings point toward potential inequities in the generation of air emissions from transport and the exposure to traffic-related air pollution, a major assumption prevailing in this analysis is in the fact that daily exposure is approximated by the NO_2 concentration at home. In fact, most individuals move around the urban area in a day (albeit spending a large portion of their time at home) and therefore are exposed to varying NO_2 concentrations at their activity locations and during travel. Besides this approach being more reflective of an individual’s daily exposure, its usefulness remains an open question in the field of epidemiology. In this study, the availability of data on individual mobility allowed us to investigate the disparity between at home concentrations and daily activity-weighted concentrations based on activity locations. We therefore compared air quality at the home location and exposures based on daily sequences of activities. We observe individuals who increase and others who decrease their daily exposure compared to the concentration at the home location. These trends were also associated with land-use characteristics at home locations. More accentuated differences between at-home and activity-weighted exposures would be expected if hourly concentration maps were used as opposed to a static map obtained from integrated sampling.

Our findings are of relevance to policy evaluation, when cities are faced with challenges such as reducing traffic emissions in future horizon scenarios the spatial variability in emissions and the responsibility for these emissions are two dimensions that are crucial for the development of meaningful policy able to reduce these emissions. The tool we propose provides a way to quantify the responsibility for emissions and the impact of individuals' emissions on other individuals' exposure. It can be used to simulate regional-level transport policies and their effects on the spatial distributions of emissions and on equity in the generation and exposure to air pollution. As cities become increasingly faced with the challenge of reducing traffic related emissions, tools such as the one we propose help identify the areas most responsible for these emissions therefore helping with the identification of priority investments. The results of our analysis are also relevant to epidemiologic studies of air pollution exposure and health effects because we demonstrate that exposure misclassification is bound to arise when we approximate daily exposure with the concentration at the home location, ignoring the activity locations.

For future extensions of the model, we propose to add multimodal and active travel trips and in-travel NO_2 exposure in the analysis of individual exposures. In-travel NO_2 exposure could account for a significant part of the daily exposure (Fruin et al., 2014). Furthermore, considering that the inequity pattern for generated NO_x and exposed NO_2 could be different from other vehicle-related pollutants with different dispersion patterns, further research is needed to understand the cumulative impacts of different pollutants. Although, the LUR map used in this study has been validated, alternative techniques such as individual monitoring using mobile technologies (Houston et al., 2013) could be an asset to validate the estimated exposures.

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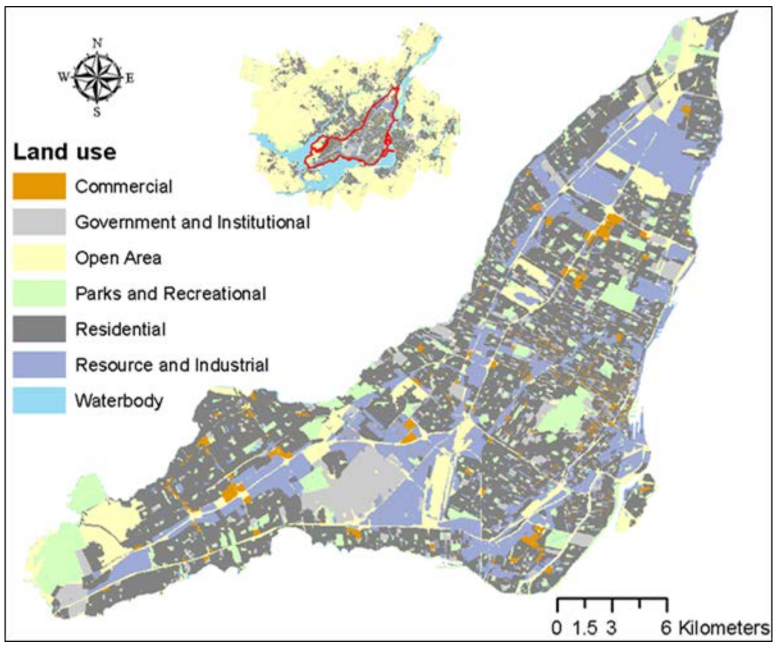


Fig. 1. Land-use map for the Montreal region featuring the Island of Montreal

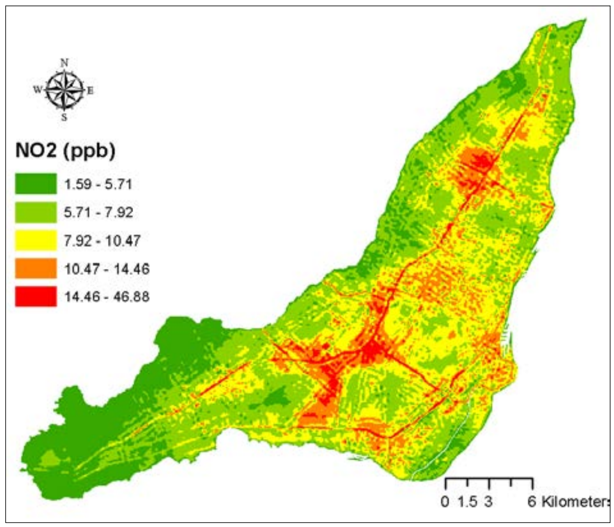
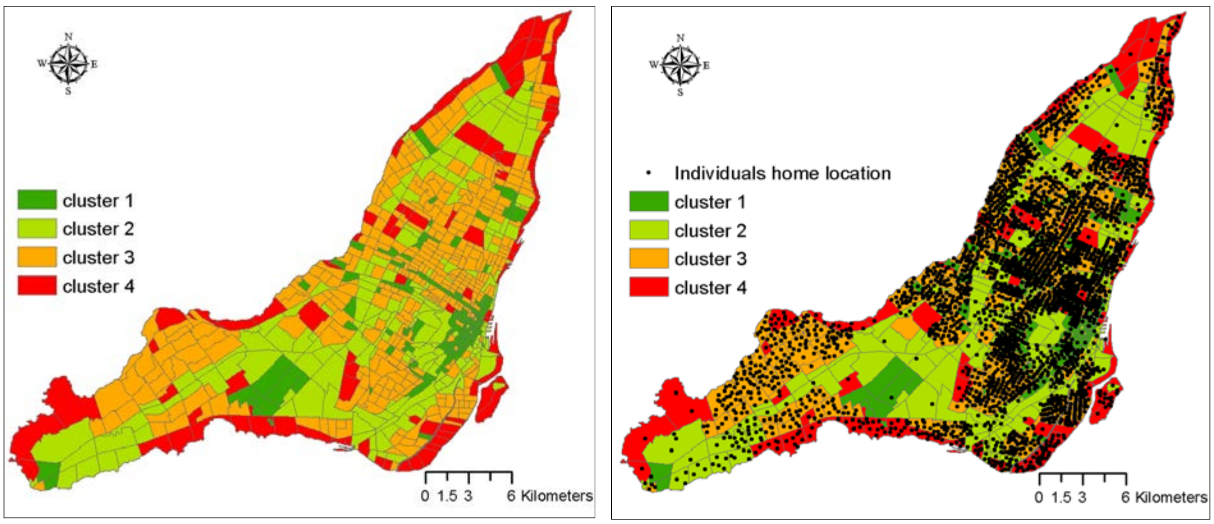


Fig. 2. Visualizing NO2 levels across the Montreal region. Average NO2 concentrations are illustrated at five different levels with green shades representing the lowest concentrations and red shades the highest concentrations.



(a) (b)

Fig. 3. Map of land-use clusters including: Cluster 1 characterized by TAZs with higher population density, higher governmental and institutional areas, denser road network and better access to metro and bus service; Cluster 2 characterized by TAZs with higher industrial density and lower residential, governmental, and institutional densities and poorer transit accessibility; Cluster 3 characterized by TAZs with higher residential density and lower industrial density; and Cluster 4 characterized by TAZs with fewer points of interest, lower population density and lower accessibility to transit service. The home locations of individuals in the OD survey are presented in Fig 3b.

	NO_x (gr)	Ln (NO_x)
N	5833	5833
Mean	10.99	0.79
Std. Error of Mean	0.21	0.01
Median	5.07	0.78
Std. Deviation	15.78	0.50
Minimum	0.00	0.00
Maximum	178.07	2.25

N: number of individuals

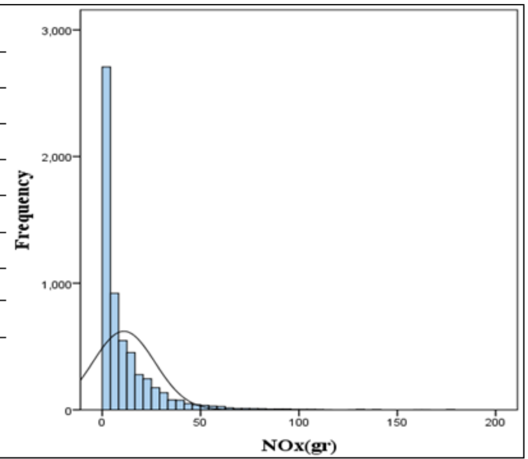


Fig. 4. Descriptive statistics for individual NOx emissions (all drivers)

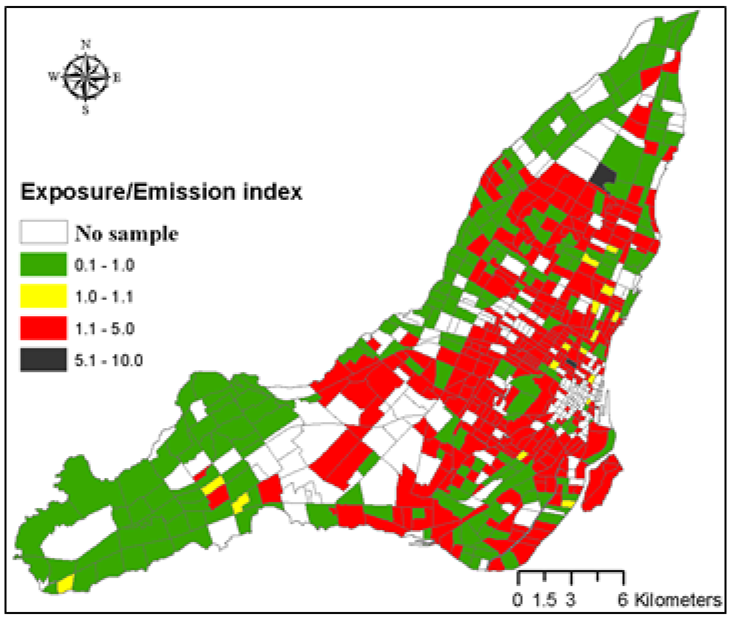


Fig. 5. Spatial variation of the exposure to emission index at a TAZ level. The index varies from 0.1 to 1; a lower index represents an area characterized as "high emitter, and low exposure" (green) and a higher index refers to "high exposure and low emissions" (red).

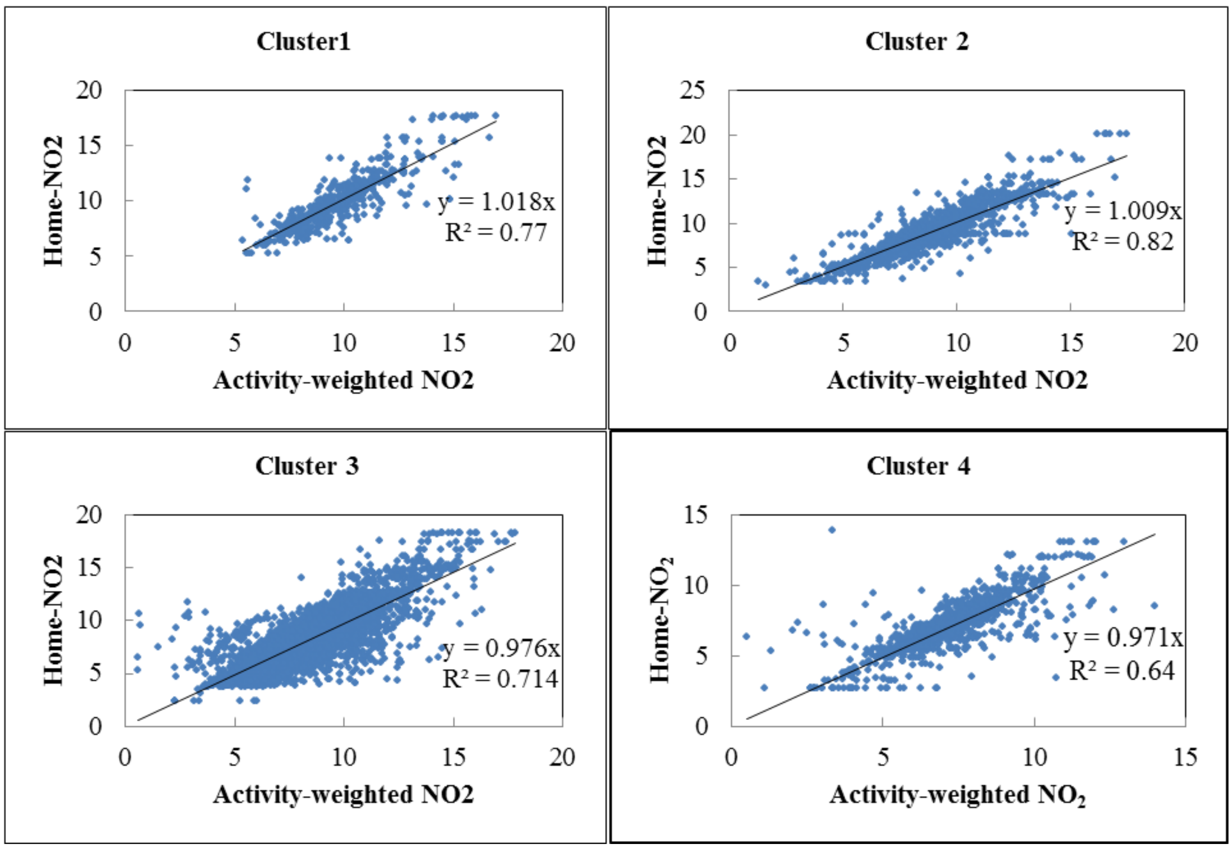


Fig. 6. Activity-weighted NO2 (ppb) versus at-home exposure (ppb) for the four clusters

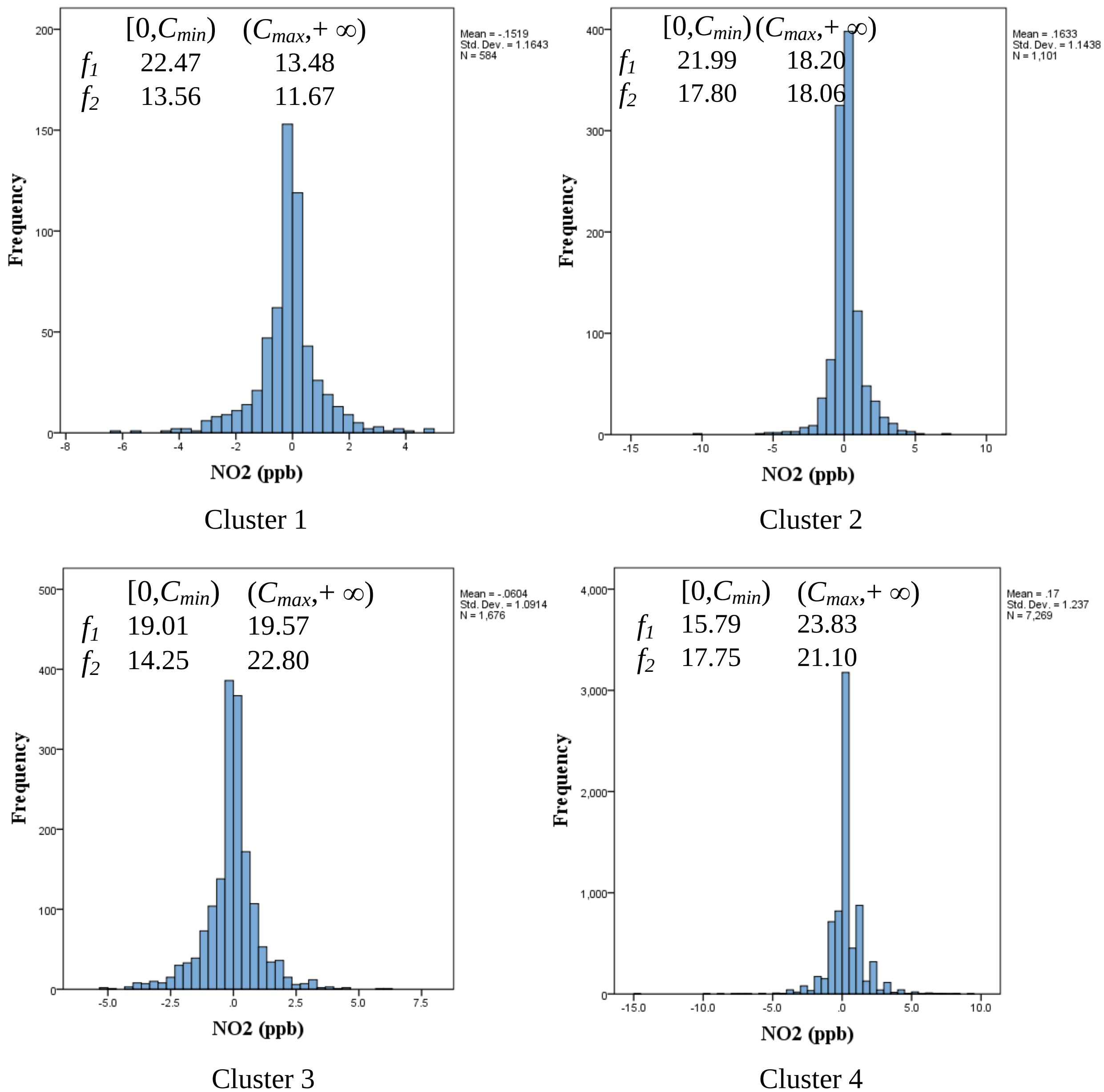


Fig. 7. Distribution of differences between activity-weighted exposures and at-home concentrations. f1 and f2 represent the percentages of drivers (f1) and of transit riders (f2) with differences between activity-weighted exposures and at-home concentrations that are higher or lower than the mean by 20%. Cmin represents the mean difference minus 20%; Cmax represents the mean difference plus 20%

Table 1. Results of factor analysis and cluster analysis

Factor Analysis Results

Factors / **Components**	Public Transit (Metro & Bus)	Public Transit (AMT Train)	Road Network	Point of Interests
Density of Bus Stops in TAZ	0.645		NA	NA
Density of STM Metro Lines in TAZ	0.827		NA	NA
Density of AMT Train Lines in TAZ		0.811	NA	NA
Density of AMT Train Stations in TAZ		0.821	NA	NA
Density of STM Metro Stations in TAZ	0.817		NA	NA
Density of Major Roads in TAZ	NA	NA	0.936	NA
Density of Highways in TAZ	NA	NA	0.837	NA
Density of Minor Roads in TAZ	NA	NA	0.736	NA
Density of Restaurants in TAZ	NA	NA	NA	0.947
Density of Bars in TAZ	NA	NA	NA	0.669
Density of All other types of Commercials	NA	NA	NA	0.883
Summary statistics				
Eigen value	1.82	1.29	2.12	2.12
% of variance accounted by the component	36.41	25.85	70.50	70.80

Cluster Analysis Results:	**Cluster 1**		**Cluster 2**		**Cluster 3**		**Cluster 4**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Number of TAZs in Cluster	171	-	275	-	659	-	447	-
Population Density	23.18	19.61	8.52	6.80	8.82	5.94	2.17	2.97
Residential Density	0.39	0.29	0.24	0.26	0.71	0.15	0.17	0.16
Industrial Density	0.11	0.16	0.49	0.31	0.08	0.09	0.04	0.07
Governmental & Institutional Density	0.27	0.33	0.02	0.06	0.046	0.07	0.013	0.04
Average Income (1000$)	59.55	27.22	76.89	43.20	59.87	18.33	67.94	16.37
Point of Interests	1.14	2.66	-0.11	0.31	-0.08	0.31	-0.25	0.07
Road Network	1.16	1.69	0.25	0.90	0.12	0.61	-0.77	0.42
Transit (Metro-Bus)	1.36	2.40	-0.15	0.38	-0.01	0.43	-0.42	0.13
Transit (AMT Train)	0.46	2.73	0.15	0.78	-0.11	0.30	-0.11	0.12

Table 2. Linear regression of NO_x emissions ($R^2 = 0.33$)

Category	Variable	β	t-stat
	Constant	0.407	19.197
Gender	Male	0.039	3.545
	Female	-	-
Status	Employed-Part-time	0.060	2.081
	Employed-Full-time	0.131	6.437
	Student	0.212	6.325
	Retired	-0.046	-1.995
	Other	-	-
Age	16-25		
	26-40		
	41-60	0.031	2.756
	>60	-	-
Vehicle Age and Type	PC ≥ 2000	-	-
	PC < 2000	0.555	44.589
	PT ≥ 2000	0.170	10.951
	PT < 2000	0.740	35.834

Table 3. Descriptive statistics for average NO_x emissions in each cluster

	Cluster			
	1	2	3	4
N	268	923	3958	684
Mean NO_x/person (gr)	9.66	10.11	11.22	11.58
Std. Error of Mean (gr)	0.83	0.49	0.26	0.62
Median (gr)	4.52	4.39	5.17	5.64
Std. Deviation (gr)	13.65	14.77	16.12	16.09
Minimum (gr)	0.00	0.00	0.00	0.00
Maximum (gr)	105.16	132.03	178.07	138.81

N: number of individuals

Table 4. Mean NO_x emissions and at-home NO_2 concentrations in each cluster

	Custer							
	1		**2**		**3**		**4**	
N	268		925		3958		684	
	NO_x (gr)	NO_2 (ppb)	NO_x (gr)	NO_2 (ppb)	NO_x (gr)	NO_2 (ppb)	NO_x (gr)	NO_2 (ppb)
Mean	9.66	9.70	10.11	8.94	11.22	7.83	11.58	7.05
Std. Error of Mean	0.83	0.15	0.49	0.09	0.26	0.04	0.62	0.07
Median	4.52	9.45	4.39	8.71	5.17	7.56	5.64	6.91
Std. Deviation	13.65	2.52	14.76	2.60	16.12	2.32	16.09	1.93
Minimum	0.00	5.14	0.00	3.04	0.00	2.24	0.00	2.63
Maximum	105.16	17.72	132.03	20.13	178.07	46.88	138.81	13.80

N: number of individuals

Table 5. Descriptive statistics for NO_2 exposure per individual in each cluster

	Clusters											
	1			**2**			**3**			**4**		
N	584			1676			7205			1101		
	NO_2-A	NO_2-H	D*%	NO_2-A	NO_2-H	D%	NO_2-A	NO_2-H	D%	NO_2-A	NO_2-H	D%
Mean	9.63	9.79	-1.63	8.90	8.96	-0.67	8.13	7.95	2.26	7.13	6.97	2.30
Std. Error of Mean	0.08	0.1	-20.00	0.05	0.06	-16.67	0.02	0.03	-33.33	0.05	0.06	-16.67
Median	9.37	9.45	-0.85	8.78	8.71	0.80	7.92	7.71	2.72	7.05	6.86	2.77
Std. Deviation	2.02	2.43	-16.87	2.19	2.55	-14.12	1.99	2.23	-10.76	1.77	1.9	-6.84
Minimum	5.39	5.23	3.06	1.3	3.04	-57.24	0.56	2.24	-75.00	0.51	2.63	-80.61
Maximum	16.94	17.72	-4.40	17.42	20.13	-13.46	17.81	18.22	-2.25	14.01	13.8	1.52

NO_2-A: activity-weighted NO_2
NO_2-H: NO_2 at home
D: relative difference, $D=\frac{\text{Activity−weighted } NO_2 - \text{Home } NO_2}{\text{Home } NO_2} \times 100$
N: number of individuals