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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.

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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 (Lewné 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.

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).

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, 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 80 m $\times$ 80 m amounting to a total of approximately 60,000 polygons). This map (Fig. 2) was used to identify the NO_2 concentration at the home