ASSESSMENT OF EXPOSURE TO TRAFFIC-RELATED AIR POLLUTION IN A LARGE URBAN AREA: IMPACTS OF INDIVIDUAL MOBILITY AND TRANSIT INVESTMENT SCENARIOS

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1. Introduction

The hypothesis that exposure to traffic-related air pollution increases the risk of developing different illnesses (e.g., cancer during childhood) has been demonstrated by various investigators (Crouse et al., 2010; Hamra et al., 2015). Therefore, the need for urban air quality prediction associated with transportation policies is important for health impact assessment (Bhalla et al., 2014; De Nazelle et al., 2011). However, only a few modeling tools are able to include projection in associated traffic related parameters (e.g., traffic allocation) in the prediction of future air quality concentrations and the impact of population mobility on urban air pollution is often ignored. Estimating the various states of air quality associated with transport policies, infrastructure investments and individuals' mobility are keys to more meaningful urban design and development.

2. Materials and Methods

Our methodology consists of four main steps: 1) Setting up an integrated transportation emission-dispersion model and generating hourly NO_2 exposure surfaces 2) Exposure analysis, which includes assigning daily trajectories to drivers, passengers, transit users and active commuters in order to estimate exposure accumulated throughout the day in the base case and future scenarios 3) Estimating the contribution of different urban areas (traffic analysis zones) to population exposure for current and future base cases (2008 and 2031) and their corresponding scenarios. Our study area is the Montreal Metropolitan Area (Figure 1).

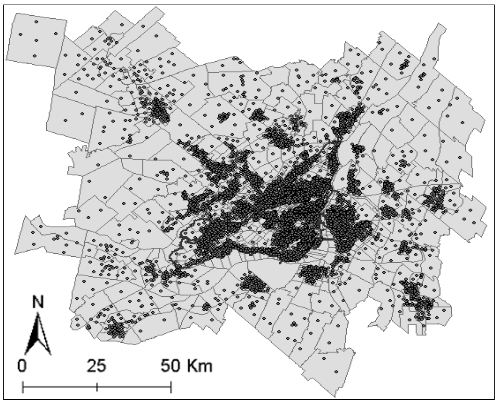

Figure 1 Montreal region and home locations of individuals in the 2008 origin-destination survey

2.1 Integrated Transportation Emission-Dispersion Modelling

The steps in the proposed framework are presented in Fig. 2 and discussed below. As can be seen, the first step involves the preparation of required information, including traffic data, land use and terrain, meteorological and observed concentrations. Next, we made use of a transportation and emissions model that includes a traffic assignment algorithm and a vehicle emissions simulator in order to estimate the emissions of NO_x (in gram) at the level of every individual vehicle based on its type, age, speed, and type of road (Sider et al., 2013). After this, a meteorological model (CALMET) is used to interpolate winds and temperatures using higher-resolution terrain elevation and land-use data and create detailed hourly meteorological fields as well as predict boundary layer parameters such as mixing height.

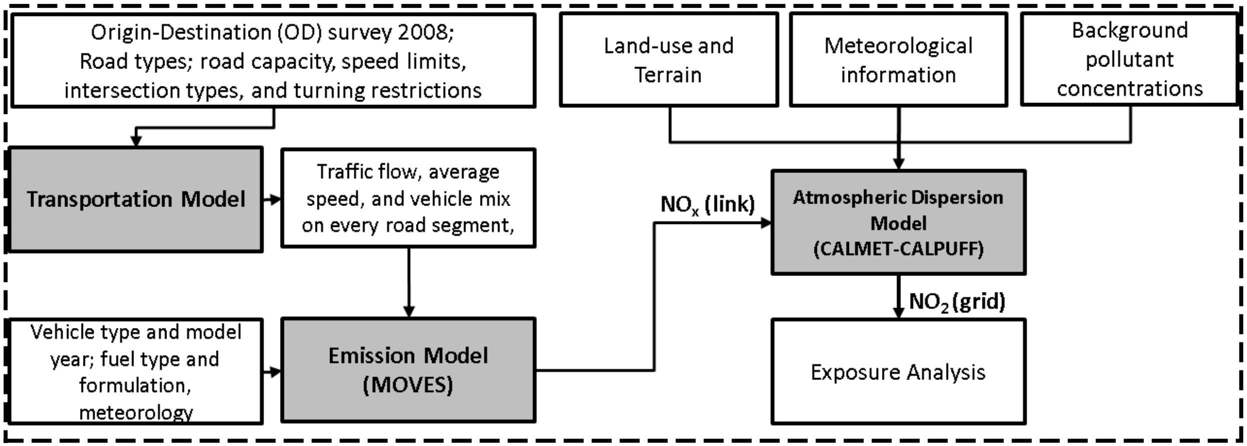

Figure 2 Schematic flowchart of the integrated transportation emission-dispersion model system

Finally, hourly emission data obtained from a transportation emission model for each link on the network and meteorological outputs are used as inputs into a dispersion model (CALPUFF) in order to simulate hourly NO_2 concentrations. The 254,000 road links in Greater Montreal were broken down to into smaller segments (less than 0.5 km) to increase the accuracy of road source modelling; in turn, the corresponding coordinates of start and end points of each link were assigned using ArcGIS v10.2. All the road segments were treated as line sources and a value of 3.5 meters was considered for the initial vertical dispersion coefficient (sigma z), therefore representing traffic-induced mixing near the roadway. Background NO_2 concentrations were also included. The simulation starts at 4:00 LST on the 7th and ends at 4:00 LST on the 14th of the following 4 months: January, April, August and October 2008. CALMET and CALPUFF share the same modeling domain. The domain extends 200 km×140 km (1 Km x 1 Km grids) centered around the Montreal Island.

2.2. Exposure analysis: base case and scenarios

We estimated NO_2 exposure for individual components of 24-hour mobility (trip, home, and activity location) to estimate the contribution of each traffic analysis zone to individual and population exposure for base case and transit scenario. We assigned the daily trajectories to drivers, passengers, transit users, active commuters. We used the origin-destination survey which includes information for a total of 66,000 households and approximately 157,000 individuals conducting a total of 355,000 daily trips across the metropolitan region. We extracted 80,000 trips (30,000 individuals) from the OD survey consisting of only single mode trips for drivers and passengers. To assign all possible paths to drivers and passengers, a path file extracted from the traffic assignment model was used. The path file includes a set of hourly matrices, indicating the multiple paths between each origin and destination. Among all possible paths between an origin/destination pair, a path that has the closest travel time to the duration of trip in the OD survey was selected and assigned to drivers and passengers using a MATLAB script. Exposures estimated based on the activity locations and trajectories that individuals take are referred to as 24-hour mobility exposures. The individual components of 24-hour mobility include home, trips and activity locations.

For 2008 scenario, we estimated the current NO_2 concentrations linked to driving trips using the year 2008 as the base year. Then, a transit scenario was simulated for 2008. We modeled 2008 base and 2008 transit scenario trips with mode choice models in order to ascertain changes in travel behaviors between these two scenarios. For this purpose, we have obtained the information about all the proposed public transit projects that are being planned or constructed around the Montreal metropolitan area. These public transit projects include extension of metro and regional light train networks as well as a new regional light train line. The proposed projects should be launched by year 2031. In this scenario, we assume that all of these public transit projects have already been built in 2008 and they are all possible options for people to choose. We allow for people to adjust their trip making decisions considering the new alternatives. Then, the same approach of traffic assignment, emission estimation and dispersion modelling is applied for this scenario.

A third simulation was introduced which describes a 2031 business as usual scenario. The projected 2031 driving trips, predicted by the mode choice model, were input to VISUM, the traffic assignment model (PTV Vision, 2009), to estimate the traffic volume, average speed and traffic mix on every road segment in 2031. In addition, a 2031 transit scenario was also introduced. In this study, changes in the NO_2 concentrations generated from traffic were then estimated.

Individual exposure to NO_2 concentrations was also estimated for home and activity locations (components of 24-hour mobility) at each individual TAZ. TAZ contribution to home and activity exposure (stop-TAZ contribution) is the sum of hourly average individual NO_2 concentrations obtained at the home and stop locations at each TAZ for all individuals. Comparing these TAZ maps for future and current scenarios shows the urban areas that might be affected by future transportation plans.

3. Results

Fig. 3 shows the percentage of changes between scenario and base case NO_2 concentrations, and scenario and base case 24-hr mobility NO_2 exposures at TAZ level for 2008 and 2031. We observed up to 51.1 and 43.3% reductions in individuals NO2 exposure, respectively for 2008 and 2031 which follows the variation in NO_2 concentrations. The transit scenario concentrations are noticeably lower at some areas considering that the mode share has been changed and mostly shifted and switched to transit mode. Our results showed that the scenarios shift towards transit especially for the trips that are affected by the new public transit alternatives (this increase is 1.86% for the total population and 16.65% for the targeted population). Therefore, we can see lower vehicle share and thus a decrease in traffic volume on the road network. As a result of lower demand for driving, lower emissions generated and as expected, the NO_2 concentrations are lower for transit scenarios. Fig. 3 also presents a reduction in the 2031 modeled exposure in comparison to the 2008 modeled exposure. The reason for this reduction can be justified based on population and active transport changes. While an important population increase occurred in the outer and inner suburbs, a slight relative population increase occurred in the densely populated Central Montreal region (9.7%; Tétreault et al., 2016). This increase in the population without a corresponding increase in the capacity of the roadway infrastructures lead to a migration in mode share from driving to active transportation which led to an increase in the average time spent in active transportation by resident of every region. The relative variation was more important in the outer and inner suburbs than in the Central Montreal region (Tétreault et al., 2016). The increase in time spent in active transportation was not only caused by an increase in the mode share but also by an increase in the time spent travelling for those practicing active transportation. We also observed an increase in the motor vehicle kilometers travelled within each region. These variations were consistently higher in the suburbs than for the Central Montreal region. Inversely, a more important reduction of NO_2 levels was observed in the Central Montreal and Inner suburb (Fig. 3). Fig. 4 shows the TAZs contribution to the individual exposure at home and activity locations which is presented by the amount of NO_2 exposure to each individual per unit area of TAZ. As presented in this figure, the Montreal downtown area has the highest levels of contribution to individual exposure in comparison with suburbs. This is consistent with the prediction of average 24-hour NO_2 concentrations (Shekarrizfard et al., 2015).

4. Conclusion

In this paper, we reported on the use of an integrated transport-emission-dispersion model for the assessment of urban areas contribution to population NO_2 exposure in Montreal, Canada. For this purpose, data from the 2008 origin-destination survey for Montreal were combined with hourly concentrations of NO_2 simulated using a dispersion model to estimate the hourly exposures of individuals 2008 and 2031 time horizon under two different transit scenarios. Our analysis showed that how a transit scenario affect an individuals' daily exposure in current time and future time horizon. Also, for both selected transit scenarios, we observed that downtown TAZs contribute higher to population exposure during the individuals' stop at the activity and home locations. Our findings are useful for urban planning applications because we can now use the proposed framework to improve urban pollution spatial analysis and evaluate the effects of various transport policy scenarios on air pollution and exposure.

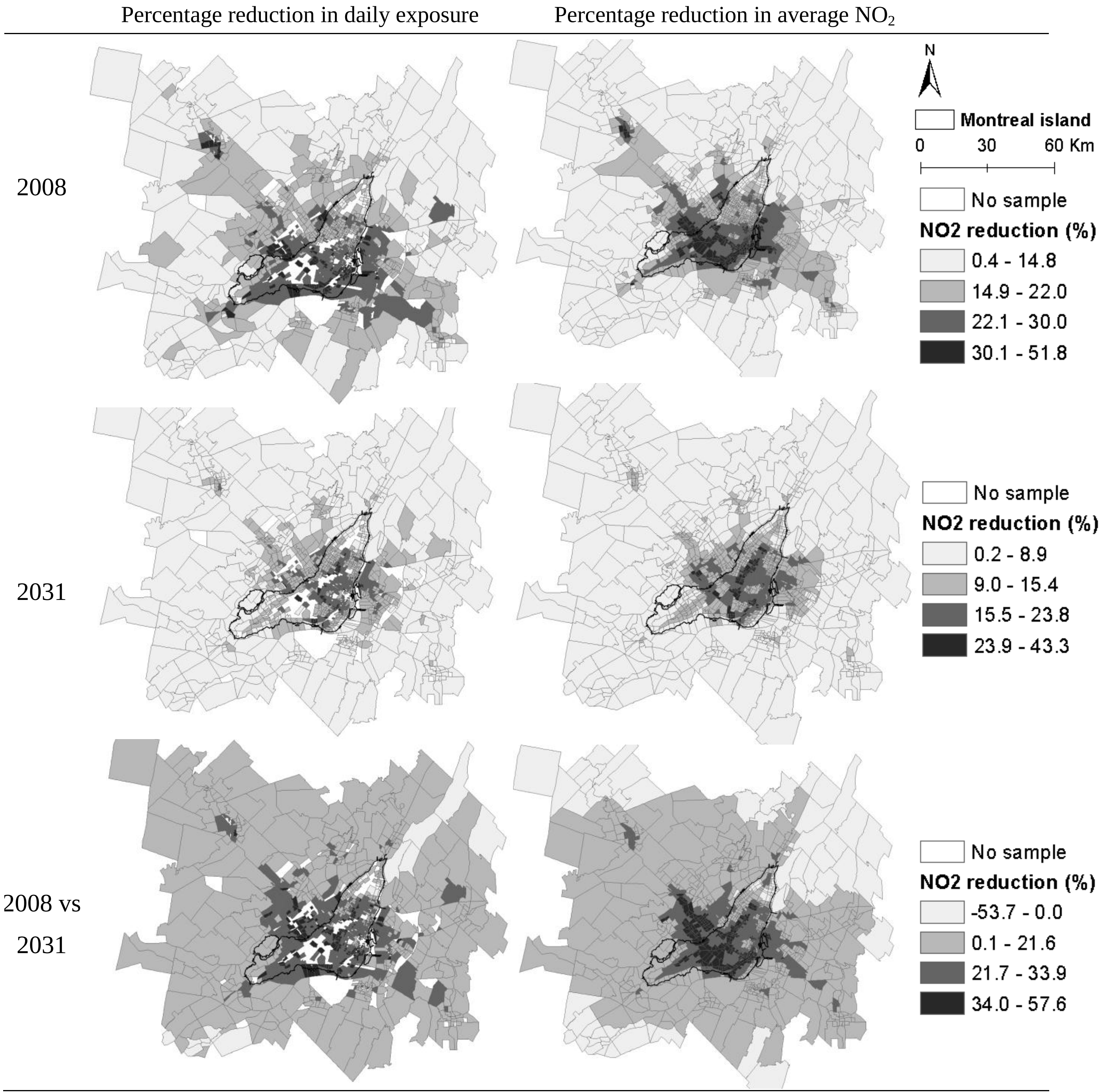

Figure 3 Change in simulated NO_2 concentrations and individuals exposure for 2008 and 2031 base case and transit scenarios

Figure 4 The TAZs contribution to the individual exposure at home and activity

5. References

Bhalla, K., Shotten, M., Cohen, A., Brauer, M., Shahraz, S., Burnett, R., Leach-Kemon, K., Freedman, G., Murray, C. 2014. Transport for health: the global burden of disease from motorized road transport.

Crouse, D.L., Goldberg, M.S., Ross, N.A., Chen, H., Labrèche, F. 2010. Postmenopausal breast cancer is associated with exposure to traffic-related air pollution in Montreal, Canada: a case-control study. Environmental health perspectives, 118(1) 1578-1583.

De Nazelle, A., Nieuwenhuijsen, M.J., Antó, J.M., Brauer, M., Briggs, D., Braun-Fahrlander, C., Cavill, N., Cooper, A.R., Desqueyroux, H., Fruin, S., 2011. Improving health through policies that promote active travel: a review of evidence to support integrated health impact assessment. Environment International, 37(4) 766-777.

Hamra, G.B., Laden, F., Cohen, A.J., Raaschou-Nielsen, O., Brauer, M., Loomis, D. 2015. Lung Cancer and Exposure to Nitrogen Dioxide and Traffic: A Systematic Review and Meta-Analysis. Environmental health perspectives.

Sider, T., Alam, A., Zukari, M., Dugum, H., Goldstein, N., Eluru, N., Hatzopoulou, M. 2013. Land-use and socio-economics as determinants of traffic emissions and individual exposure to air pollution. Journal of Transport Geography, 33 230-239.

Shekarrizfard, M., Hatzopoulou, M. 2015. Air Quality Simulation of Traffic Related Emissions: Application of Fine-Scaled Dispersion Modelling. Canadian Transportation Research Forum (CTRF), Conference-Montreal-May 2015.

Tétreault, L.F, Eluru, N, Hatzopoulou, M, Morency, P, Plante C, Reynaud, F,Shekarrizfard, M, S. Yasmin, Fimani, A, Drouin, L,Pelletier, A, Goudreau, S, Tessier, F, Gauvin, L, and Smargiassi, A. 2016. Health impacts and benefits of the current greater Montreal transportation system in 2008 and 2031 (under preparation).