THE IMPACT OF IMPROVING PUBLIC TRANSPORTATION ON DECREASING AIR POLLUTION AND GREENHOUSE GASES EMISSIONS: THE CASE OF SAO PAULO, BRAZIL

Flávia N. D. Ribeiro*, Júlio B. Chiquetto, Dominique Mouette, Natasha M. Valdambrini
School of Arts, Sciences, and Humanities, University of Sao Paulo, SP, Brazil

Pedro G. Machado
Sustainable Gas Institute, Imperial College London, South Kensington Campus, London SW7 2AZ, UK

Jacyra Soares
Institute of Astronomy, Geophysics, and Atmospheric Sciences, University of Sao Paulo, SP, Brazil

1. INTRODUCTION

The Metropolitan Area of Sao Paulo (MASP) is a conurbation of 39 municipalities and has a population of 21 million inhabitants in the Southeast Region of Brazil. It frequently presents degraded air quality and the pollutants that contribute the most to unhealthy conditions are ozone (O_3) and particulate matter (PM), according to the Environmental Company of Sao Paulo State (CETESB, 2020). Using the Company standards, the daily average PM presented 27 exceedances from 2011 to 2020 and O_3 presented 168 exceedances for the eight-hour average. However, using the previous World Health Organization standards (WHO, 2006), PM presented 757 exceedances and O_3 presented 824 exceedances in 10 years. These number would be even higher for the new WHO Guidelines (WHO, 2021).

Air pollution is a known cause of an increase in mortality and morbidity in Sao Paulo (Miranda et al. 2012), health-related economic costs, and unequal impacts on public health, being worse for people in social vulnerability (Chiquetto et al. 2019), adding to environmental and social injustice.

Annual estimates of vehicular emissions are performed by CETESB, divided by type of vehicle and fuel. The MASP fleet consists of 5,3 million cars, 885 thousand motorcycles, 908 thousand light commercial vehicles, 172 thousand trucks, and 55 thousand buses. The Company also uses a fixed sources inventory from 2008 that includes industry and fuel base emissions to assess air quality in the state.

*Contact information: Av. Arlindo Béttio, 1000, Vila Guaraciaba, São Paulo, SP, Brasil. CEP: 02357-000
flaviaribeiro@usp.br

The inventory for 2019 is presented in Table 1 and indicates that vehicles were responsible for 96% of carbon monoxide (CO) inventoried emissions, 73% of hydrocarbons (HC), 65% of nitrogen oxides (NO_X), 25% of PM, and 11% of sulfur oxides.

The city of Sao Paulo, the largest in the MASP with 12 million inhabitants, is part of the C40 Cities network and has prepared a Plan for Climate Action to align the municipal greenhouse gases (GHG) mitigation actions with the Paris Agreement (Sao Paulo, 2019). The city commits to decrease 45% of GHG emissions by 2030, to be a carbon-free city by 2050, to adapt to climate change impacts, and to provide equity in the distribution of social-environmental improvements. The road transportation GHG emissions corresponded to 37% of the total emissions inventoried for the State of Sao Paulo in 2008 (CETESB, 2011). The evolution of yearly vehicular GHG emissions in the State is presented in Fig. 1. The yearly variations are strongly influenced by sugarcane ethanol usage. As the state is an important producer of sugarcane in the country, ethanol combustion emissions are considered compensated by agriculture and CETESB excludes them from the inventory.

Table 1: Emissions inventory in 1000 metric tons per year. Source: CETESB (2020).

Source	CO	HC	NO_X	PM	SO_X
Vehicular (2019)	112.97	24.89	48.27	1.22	0.72
Industry (2008)	4.18	5.60	26.10	3.57	5.59
Fuel base (2008)		3.68			
Total	117.15	34.17	74.37	4.79	6.31

MASP has a substantial public transportation network, including buses, subway, and metropolitan trains. Nevertheless, it is not sufficient for the population, that constantly faces crowded buses and trains, even during the pandemic. An origin-destination performed by the subway company in 2017 showed that more than 49 million travels are performed in a typical working day in the MASP (Metro, 2019). Among these, 67.3% area motorized travels, including private and public transportation. Train and subway are 11.6% of the travels and are considered less polluting means of transportation because they are electric.

An expansion plan publicized by the state would implement new lines and stations by 2025 to provide access to trail transportation to the population living near the future stations and potentially decrease the use of motorized private transport (PITU, 2025). Therefore, the main goal of this work is to assess the impacts of transport policies for modal change near subway and metropolitan train stations on air quality and GHG emissions.

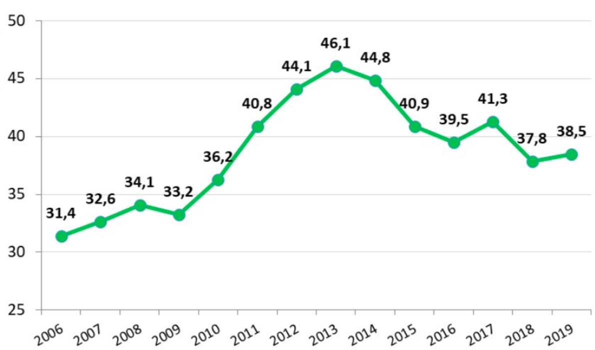

Fig. 1. Yearly GHG vehicular emissions in the State of São Paulo. Source: CETESB, 2020.

2. METHODOLOGY

The methodology followed two steps: the design of the scenarios and the air quality simulations.

2.1 Scenarios

Three scenarios were performed to assess the impact of public policies to support the use of public and active modes: the baseline scenario, hereafter called CONTROL; a scenario to simulate the expansion of the trail network, hereafter called EXC scenario; a scenario to simulate the expansion of the trail network and increased use of active and trail modes of transportation, a progressive scenario hereafter called PRG.

CONTROL scenario used vehicular emissions estimated for 2025 using the methodology applied by Ribeiro et al. (2021). The authors used trends of the vehicular fleet to calculate future emissions.

EXC considered a decrease in car emissions near the planned but non-existent stations, to simulate the effect of the trail network expansion. To calculate the percentage of decrease, data from the subway origin-destination survey was used. We counted car trips that begin(end) in a 1.3 km radius buffer centered in planned but non-existent stations and that end(begin) in a 1.3 km radius buffer centered in any other station and considered that they would be changed to a trail trip complemented by an active mode trip (cycling or walking). This scenario represented a reduction of 5% of all car trips. Fig. 2 shows the buffers centered in existent stations in white and planned but non-existent stations in red.

PRG assumes that all the car trips that begin and end near a 1.3 km radius buffer centered in a planned or existent station are changed to a trail trip. This reduces 18% of all car trips. The 1.3 km radius for the buffers was determined to represent a 15 minutes walk or even shorter bicycle trip. This scenario was designed to represent a promotion of active and public transportation modes.

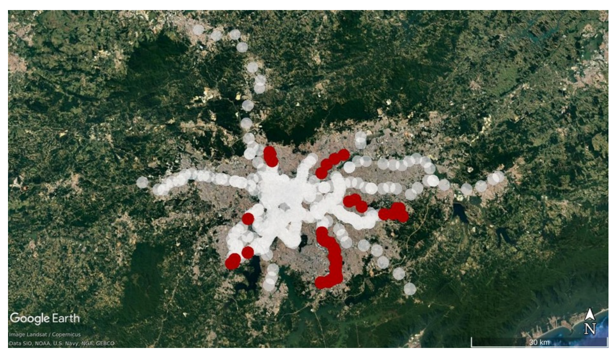

Fig. 2: Satellite image of the MASP. Red circles are 1.3 km buffers around planned but non-existent trail stations and white circles are buffers around existent stations. Source: Google Earth.

After calculating the emissions reduction for each scenario, the new values were applied to the relating buffers using QGIS (2021), Surrogate Tools, and SMOKE (https://cmascenter.org/) to prepare emissions for the air quality simulations.

2.2 Air quality simulations

The air quality simulations were performed using the WRF-Chem model (Grell et al. 2005) version 4.1.5. A 3 domains nested simulation with 100, 101, and 100 horizontal grid points, 15 km, 3 km, and 1 km horizontal spacing, and 50 vertical levels. Atmospheric initial and boundary conditions were obtained from NCEP global model (NCEP, 2015) and air quality initial and boundary conditions from CAM-CHEM (Buckhholz et al., 2019; Emmons et al., 2020). The simulation period started on 02 Jul 2018 and ended on 10 Jul 2018, during austral winter. The chemical mechanism option was CBMZ without dimethylsulfide (DMS) and MOSAIC with 8 bins.

3. RESULTS

The results are divided into vehicular emission reductions and air quality results.

3.1 Vehicular emission reductions

Table 2 shows the total estimated vehicular emission for each scenario and percentage of reduction compared to CONTROL. The greatest reduction is for CO and volatile organic compounds (VOC), such as nitrous acid (HONO), because cars in the MASP use either ethanol or gasohol. Gasohol is a mixture of 27% ethanol and 73% of gasoline. The reduction is different for each scenario because the types and quantity of roads differ for each buffer. As cars are not considered an important source of PM, reductions in PM are small.

Table 2: Total vehicular emission for scenarios CONTROL, EXC, and PRG and percentage of reduction for EXC and PRG in comparison with CONTROL.

Pollutant (short ton)	**CONTROL**	**EXC**	**PRG**
CO	100,334	96,570 (-3.7%)	87,929 (-12.4%)
NO_X	38,801	35,588 (-8.3%)	34,757 (-10.4%)
SO_2	990	913 (-7.8%)	893 (-9.8%)
VOC	17,382	16,701 (-3.9%)	15,184 (-12.6%)
PM	773	704 (-8.9%)	697 (-9.8%)
CO_{2eq}	26,150,946	24,782,278 (-5.2%)	23,079,529 (-11.7%)

Concerning GHG, the PRG scenario points to a 12% reduction in vehicular emission as the EXC scenario points to a 5% reduction. Even considering that most of the reduction happens inside Sao Paulo city, it is not sufficient to comply with the Plan for Climate Action and additional measures must be taken. Reductions in ethanol combustion contribution to GHG are not officially computed because it is considered compensated by agriculture.

Figure 3 shows the emissions difference between the CONTROL and EXC scenarios for several pollutants. The reductions match the red circles in Fig. 1. However, the differences in reduction are related to differences in quantity and type of roads present in each buffer. The EXC scenario presents reductions in peripheral areas and not in the center of the MASP.

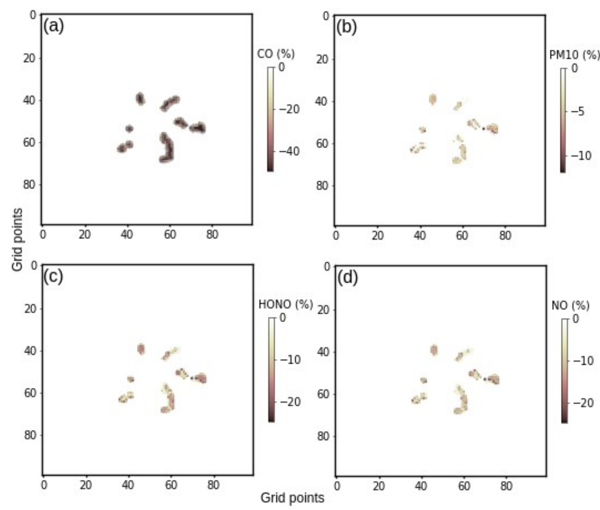

Fig. 3: Difference between CONTROL and EXC emissions for (a) CO, (b) coarse PM (PM10), (c) nitrous acid (HONO), and (d) NO.

PRG scenario, presented in Fig. 4, shows substantial reductions in the center of the MASP, where the road density is higher. However, particularly for the northern buffers, there are also high reduction values in more peripheral areas.

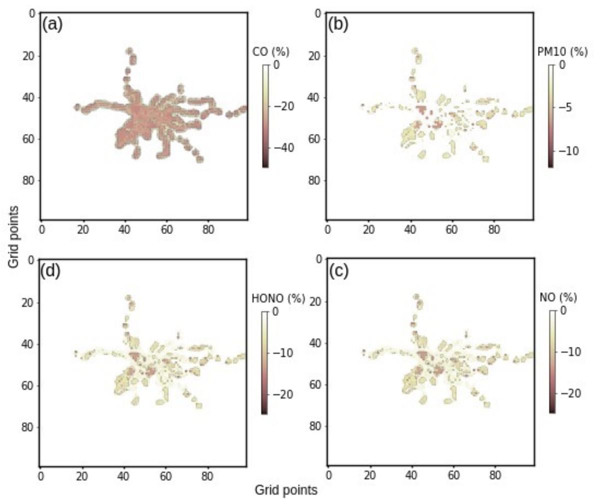

Fig. 4: Difference between CONTROL and PRG emissions for (a) CO, (b) coarse PM (PM10), (c) nitrous acid (HONO), and (d) NO.

3.2 Air quality results

Figure 5 presents the concentration average for the whole simulated period for CO, fine PM ($PM_{2.5}$), NO_2, and O_3. The center of the domain shows the greatest concentrations of CO, $PM_{2.5}$, and NO_2, and the lowest concentrations of O_3. $PM_{2.5}$ presents also high concentrations in the southeast part of the domain, near the coastline.

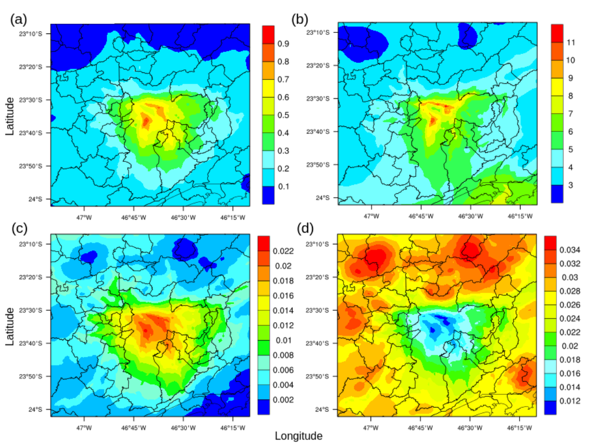

Fig. 5: Average concentration for CONTROL scenario of (a) CO, (b) $PM_{2.5}$, (c) NO_2, and (d) O_3.

Figure 6 presents the difference between the CONTROL scenario average and the EXC scenario average. For CO it is noticeable that the greatest reductions, up to 15%, are mainly located inside the buffers, but reductions up to 3% are spread over the whole city and neighboring areas, particularly in the southeast. This pattern is related to the predominant circulations in Sao Paulo from the northwest and southeast (Oliveira et al., 2003).

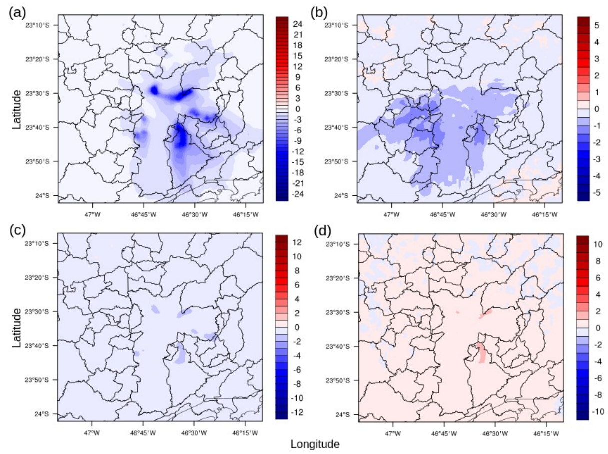

Fig. 6: Percentage difference in average concentration between CONTROL and EXC for (a) CO, (b) $PM_{2.5}$, (c) NO_2, and (d) O_3.

For $PM_{2.5}$, the concentration reduction reaches only 2% and is more spread than for CO. This result may have a contribution from secondary aerosols. NO_2 concentration reduction is also small, reaching only 1%. O_3 presents a negligible increase in concentration, reaching only 1% in two small areas that coincide with a small reduction in NO_2 concentrations.

PRG scenario (Fig. 7) presents higher reduction values for CO, $PM_{2.5}$, and NO_2 and higher a increase in O_3 compared with EXC. The changes are more substantial in the center of the MASP, related to the reductions in emission, but their influence reaches the peripheral areas.

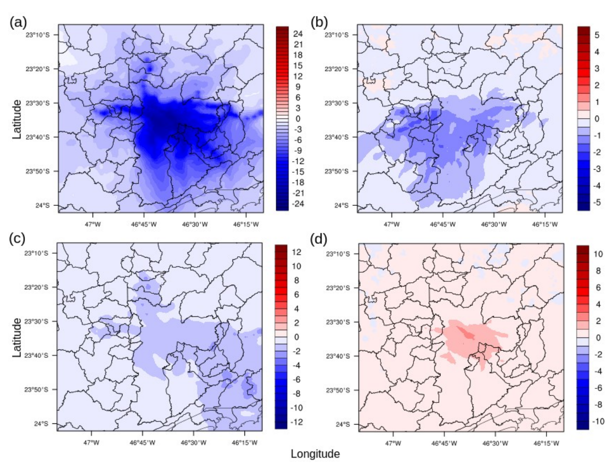

Fig. 7: Percentage difference in average concentration between CONTROL and PRG for (a) CO, (b) $PM_{2.5}$, (c) NO_2, and (d) O_3.

For CO, there is a substantial reduction of approximately 20% in the center and almost the whole domain presents concentrations reductions. $PM_{2.5}$ reaches 2.5% reductions east from Sao Paulo city, but almost the whole city of Sao Paulo presents approximately 1% reduction. NO2 maximum concentration reduction is 2.5, particularly over the southeast part of the domain, but the central part also shows approximately 1% reduction. O_3 presents up to a 2% increase, but it is located in the areas the O_3 concentration is the lowest (Fig. 5). Most of the MASP does not present a change in O_3 average concentrations.

4. DISCUSSION AND CONCLUSIONS

The present work aimed to assess the impacts of transport policies for modal change near subway and metropolitan train stations on air quality and GHG emissions by devising two alternative scenarios: one to represent the planned expansion of subway and train lines and stations and other to suggest a more progressive approach towards an increase in active and public modes of transportation and decrease in motorized and private modes of transportation. The implication of the scenarios to GHG emissions decrease is positive, but still not sufficient, because even the progressive scenario pointed to only a 12% reduction in GHG emissions. If Sao Paulo city is to comply with its Plan for Climate Action other measures should be taken as well. As private cars in the MASP use mainly gasohol and ethanol, the greatest reduction in emissions by decreasing the usage of cars is on CO and VOC emissions and CO concentrations. O_3 shows a slight increase, due to its non-linear behavior with emissions reduction. Its increase happens mainly in areas where NO_X is reduced, corroborating previous studies (Sánchez-Ccoyllo et al., 2006; Orlando et al., 2010; Chiquetto et al., 2020). Fortunately, these areas are also the ones that present the lowest concentrations of O_3. It is important to notice that the simulations were performed for the winter when O_3 concentrations are the lowest during the year. Additional simulations during summer should be performed to assess the impact on O_3 concentrations.

Despite the low percentages of decrease of some pollutant concentrations, the planned expansion of the trail network could help decrease pollutants concentrations in areas that are already neglected in terms of access to public transportation. Therefore, improvements in accessibility and air quality are co-benefits that may help decrease social inequality.

Additionally, when promoting a change in pollutants emission, a careful look at precursors of secondary pollutants must be taken, as evidenced by the results of the progressive scenario.

Infrastructure is needed to provide accessibility. Nevertheless, just providing transportation infrastructure does not ensure reductions in car activity. Other policies are needed to promote active and public transportation modes.

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