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FUTURE SCENARIOS IN VEHICULAR EMISSIONS AND THE IMPACT OF NEW VEHICLE TECHNOLOGIES, FUEL AND MOBILITY TRENDS ON AIR QUALITY

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*1. INTRODUCTION

The Metropolitan Region of São Paulo is one of the largest conurbations of the world (Fig. 1), with more than 21 million inhabitants (46 % of the population of the state of São Paulo), and more than 7 million vehicles (63 % of the fleet of the state). According to the Environmental Agency of the State of São Paulo (CETESB, 2018), its fleet emits annually more than 124,000 metric tons of carbon monoxide (CO), 46,000 tons of nitrogen oxides (NOx), 1,000 tons of coarse particulate matter (PM10), 1,000 tons of sulfur dioxide (SO2), 28,000 tons of volatile organic compounds (VOC), including evaporative emissions and emissions during supply. Vehicles also emit more than 14 millions of tons of carbon dioxide equivalent (CO2eq) and, according to Ferreira et al. (2010), contribute to half of the anthropogenic heat.

The motivation for the present work was the need to quantify the effect of public policies and urban mobility planning on vehicular emissions. At the national level, the National Council for the Environment (CONAMA) has established programs to control vehicular emissions that has implementation phases with increasingly restrictive limits for emission factors, called PROCONVE (CONAMA, 1986) and PROMOT (CONAMA, 2002). The use of biofuels, such as ethanol and biodiesel, is substantial: gasoline vehicles use a mixture of 27% ethanol and 73% gasoline, called gasohol, as flex-fuel vehicles may use ethanol, gasohol or a mixture of the two; diesel used in transportation has 8 % of biodiesel. Additionally, a great number of research projects on biofuels are being developed (Greggio Ferreira, 2017). At the municipal level, the Municipal Urban Mobility Plan (São Paulo, 2016) prioritizes public transport and active modes of transportation, such as riding bicycles and walking. Recently, a municipal law has determined a discount in the taxes of electric passenger cars (São Paulo, 2015). Another municipal law establishes a plan to decrease buses in public transportation emission:

- decrease CO2 emissions in 50 % by 2028 and in 100 % by 2038;
- decrease PM emissions in 90% by 2028 and in 95% by 2038;
- decrease NOx in 80% by 2828 and in 95% by 2038.

To achieve these goals, the bus fleet may be entirely changed to electric. Additionally, in 2019, a working group started the development of a Plan for Climate Action, with the help of the C40 Cities network, aiming to have a carbon free city by 2050, while adapting to climate change impacts and equally distributing social-environment improvements (São Paulo, 2019).

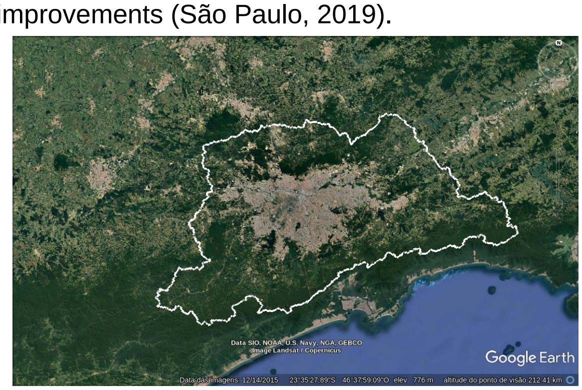

Figure 1: The Metropolitan Region of São Paulo.

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However, to evaluate the impact of these policies, a comprehensive calculation of future emission inventories must be performed. Therefore, the main goal of the present work is to determine emission abatements for future scenarios to better inform policy makers, considering pollutants, greenhouse gases (GHG) and the vehicular contribution in anthropogenic heat. The influence of changes in fuels on secondary pollutants, such as ozone (O3), is also considered. The future scenarios include changes in fuel, engine and modes of transportation.

2. METHODOLOGY

Three steps were performed to create the future scenarios emissions: the active fleet trends were determined; future scenarios were designed; and emission inventories were calculated. Finally, simulations were performed to evaluate O3 concentrations.

2.1 Active fleet trend

The methodology to quantify future emissions is based on the tendency of the last 12 years of the active fleet. Active fleet is a concept used by CETESB, that applies a scrap curve on the registered fleet. A regression was performed for each type of vehicle and fuel and the resulting function was applied to estimate total fleet. The age of the vehicles of the previous year was updated and the remaining vehicles to reach the estimated total were considered new. For increasing tendencies, logarithmic functions were fit. For decreasing tendencies, exponential functions were used.

2.2 Future scenarios

The business as usual (BAU) future scenario only considered the evolution of the active fleet, based on the trends previously determined, and that the renovation of the fleet will lead to lower average emission factors, because older vehicles were produced when the limits for emission factors were less restrictive. To develop the alternative scenario (ALT), an interdisciplinary group of researchers discussed the trends in technology, fuel, mobility and public policies. The potential changes selected were: electrification of all of the buses and of 40% of passenger cars; 90% of use of ethanol among flex-fuel cars; and, based on a survey performed by a consultancy agency (Kantar, 2020), a decrease of 48% of passenger cars activity and an increase of 23% in buses activity. The scenario was modeled by changing vehicle activity and emission factors.

2.3 Emission inventories

For the calculations of the annual emission inventories, the methodology of CETESB was used, to allow the comparison between past and future scenarios. Regarding flex-fuel vehicles, the choice of fuel is based on the fuel price. For future business as usual (BAU) scenario, the same proportion calculated by CETESB in 2017 was used: 50 % of flex-fuel vehicles used ethanol and 50 % used gasohol. The inventory uses a bottom-up approach for CO, NOx, PM, HC, aldehydes (RCHO), nitrous oxide (N2O), and methane (CH4), following Eq. 1:

$$Etotp = \Sigma v,f,aEFp,v,f,a*Qv,f,a*Av,f,a \qquad (1)$$

where *Etotp* is the total annual emission of pollutant *p*, *EF* is the emission factor for each pollutant, vehicle type (*v*), fuel (*f*), and age (*a*), *Q* is the number of vehicles and *A* is the activity. Only vehicles up to 40 years of age are considered. SO2, carbon dioxide (CO2), and VOC emissions during supply emissions are calculated using a top-down approach, multiplying a emission factor to the total consumption of fuel.
Vehicular anthropogenic heat calculations were based on the methodology of Ferreira et al. (2010), following Eqs. 2a,b:

$$VAH=(\Sigma v,a,f\ NHCf*\rho f*Qv,f,a*Av,f,a/Fev,f,a)/Ar \qquad (2a)$$

$$VAHel=(\Sigma v,a\ NHCELv*Qv,a*Av,a)/Ar \qquad (2b)$$

where *VAH* is the total annual emission of vehicular anthropogenic heat, *NHC* is the net heat released for each vehicle type (*v*), fuel (*f*), and age (*a*), *ρ* is the fuel density, *Fe* is the fuel economy and *Ar* is the area of the Metropolitan Region. *VAHel* is the anthropogenic heat for electric vehicles and *NHCEL* is the net heat released for electric vehicles.
The evaporative emissions considered the diurnal

phase emission factor (*D*) and average distance per ride (*AR*), hot soak phase (*HS*) and running losses (*Rl*), following Eq. 3:

$$Eevap = \Sigma v,a,f\ Qv,a,f*(366*Dv,a,f + ARv,a,f(HSv,a,f + Rlv,a,f)) \quad (3)$$

CO2eq is calculated considering also N2O and CH4 emissions, following Eq. 4:

$$CO2eq = \Sigma v,a,f\ CO2v,a,f + 310*N2Ov,a,f + 21*CH4v,a,f \quad (4)$$

2.4 Air quality simulations

The impact of emission abatements in secondary pollutants is evaluated using air quality simulations with the chemistry model WRF-CHEM (Grell et al. 9999). Two simulations were performed, changing only the anthropogenic emission totals calculated in the previous steps. The simulations started in 2018/01/13 and ended in 2018/01/15. Only one domain was used, with 200 by 200 km of area and 1x1km grid. For these simulations, the anthropogenic heat was not included. Initial and boundary conditions were obtained from GFS global model data (NCEP, 2015). The total annual emissions were spatially distributed, according to the types and lengths of roads from OpenStreetMap (2015), and temporally evolved using SMOKE (2015) model.

3. RESULTS

3.1 Active fleet trend

The active fleet is increasing, mainly due to the flex-fuel passenger cars trend (Fig. 2). Buses present a decreasing trend, as some types of trucks. Flex-fuel commercial light duty vehicles and motorcycle are also increasing.

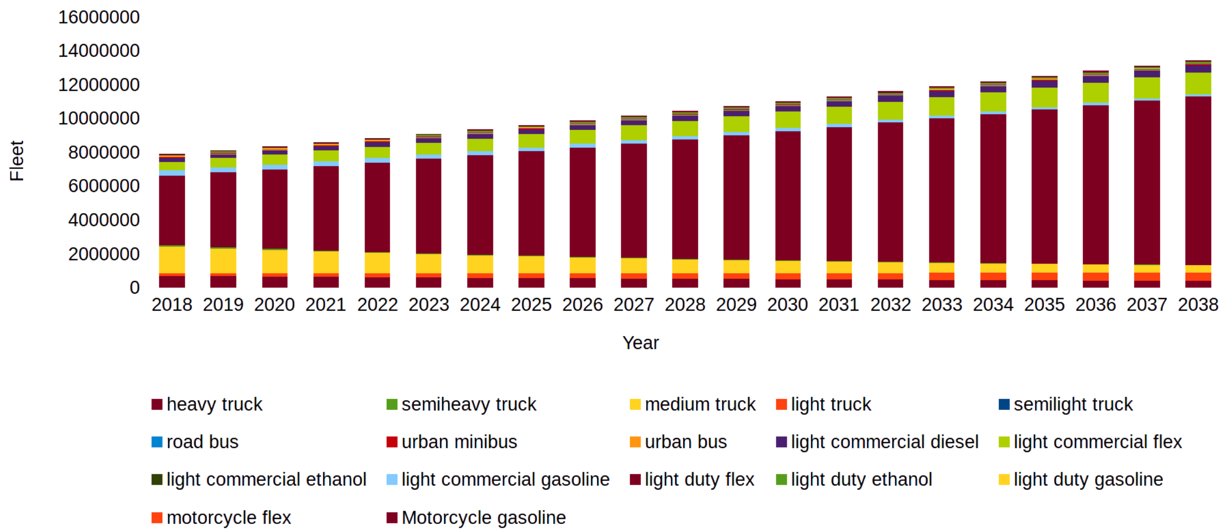

Figure 2: Evolution of the active fleet of the MRSP.

3.2 BAU emissions in 2038

For the BAU scenario in 2038, most of the pollutants present a decrease (CO, NOx, PM10, SO2, NMHC and evaporative VOC). This is due to the renewal of the fleet, that causes a higher number of vehicles with lower emission factors than in 2017. This result demonstrates long term effects of the National Emission Control Program. Additionally, as the flex-fuel fleet increases, the use of ethanol is higher, causing an increase in RCHO emission and VOC evaporated during supply. Vehicular anthropogenic heat increases in 50% and carbon dioxide in 40%. If no action is taken, the MRSP will increase its contribution to climate change and to urban heat island (UHI) intensity, risking a more frequent occurrence of synergistic local effects between global warming and UHI.

Table 1: Total annual emissions evolution for BAU scenario from 2017 to 2038.

Emission	2017	2038	Variation (%)
CO (t)	118,344	105,574	**-11**
NOx (t)	52,821	29,442	**-44**
PM10 (t)	1,372	340	**-73**
SO2 (t)	1,395	443	**-68**
NMHC (t)	13,233	10,880	**-18**
RCHO (t)	632	836	**+32**
Evaporative (t)	7,955	5,295	**-43**
Supply (t)	6,283	9,213	**+47**
VAH (MJ m^{-2})	36.77	55.33	**+50**
CO2eq (1,000 t)	15,874	22,241	**+40**

3.3 Alternative scenario emissions in 2038

For the ALT scenario in 2038, when compared to 2017, all the emissions are lower. Electric buses and cars help decrease PM10 even further.

Table 2: Total annual emissions evolution for ALT and variation between ALT and BAU in 2017 and ALT and BAU in 2038.

Emission	ALT	Variation 2038 (%)	Variation 2017 (%)
CO (t)	53,227	-49	**-55**
NOx (t)	19,972	-32	**-62**
PM10 (t)	207	-39	**-85**
SO2 (t)	217	-51	**-84**
NMHC (t)	10,853	-0,2	**-18**
RCHO (t)	614	-27	**-3**
Evaporative (t)	3,200	-39	**-60**
Supply (t)	3,223	-65	**-49**
VAH (MJ m^{-2})	31.84	-42	**-8**
CO2eq (1,000 t)	9,909	-55	**-38**

Decrease in the activity of passenger cars help decrease CO and VOC, even with the increased use of ethanol in flex-fuel vehicles. Anthropogenic heat will slightly decrease, because of electrification and decrease in passenger cars activity. For CO2eq, this scenario presents 38% of decrease. This is an important result, because the MRSP may go from increasing its climate change contribution to decreasing it in almost 40%.

3.4 Air quality simulations

Figure 3 presents the concentration of O3 in January 15th 2018 for different times of the day. On the right, the ALT scenario presents concentrations very similar to those of the BAU scenario (on the left). These results show that the ALT scenario is capable of reducing primary pollutants, GHG, and anthropogenic heat, while O3 concentrations are not substantially affected in comparison to the BAU scenario. This is an interesting result, because recent events of decrease in primary pollutants emission, particularly during the first weeks of social isolation due to the Covid-19 pandemic in March 2020, lead to an increase in O3 concentrations (Nakata & Urban, 2020). The ALT scenario points to decrease in primary pollutants without an increase in O3.

4. DISCUSSION AND CONCLUSIONS

This work has shown that the emission factor limitation policies have long term results, especially if they are updated. If no action is taken, transportation emissions of GHG and vehicular anthropogenic heat in the MRSP may increase. These two effects combined may point to synergistic effects between UHI and climate change extreme events. The combination of actions in the alternative scenario, such as electrification of the transportation sector, increase in biofuel usage, and decrease in private vehicles activity, presents promising results in pollutants, GHG and heat abatement. O3 may not be substantially affected by the alternative scenario of primary pollutants abatement.

Future scenarios were designed before the Covid-19 pandemic occurred and it is still uncertain how the emissions will respond. However, this methodology may be quickly adjusted and other scenarios may be evaluated.

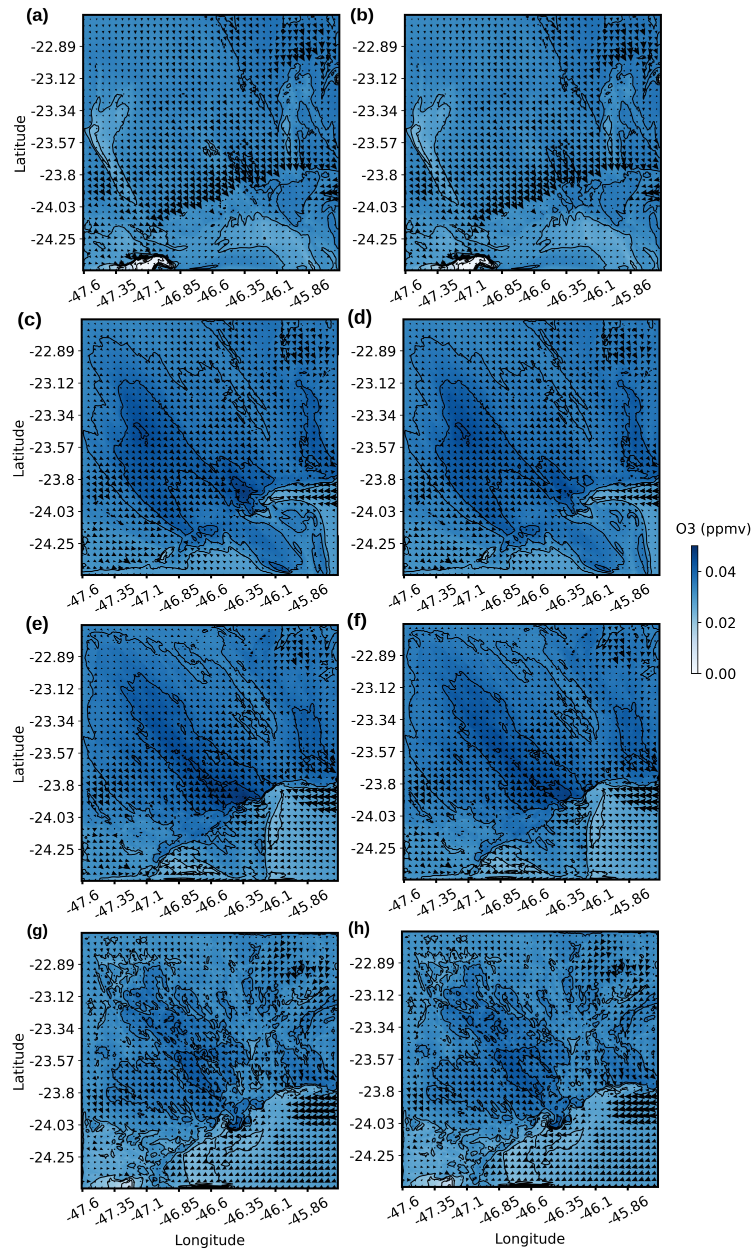

Figure 3: Ozone concentration in 2018/01/15 at (a) and (b) 0900LT; (c) and (d) 1200LT; (e) and (f) 1500LT; and (g) and (h) 1800LT; for the BAU scenario on the left (a, c, e, g) and for the ALT scenario on the right (b, d, f, h).

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REFERENCES

CONAMA. (1986). Resolution n.18 1986/05/06.

http://www2.mma.gov.br/port/conama/res/res86/res1886.html. Access: 2020/10/09. (Portuguese).

CONAMA. (2002). Resolution n. 297 2002/02/26. https://www.mma.gov.br/estruturas/163/_arquivos/promot_163.pdf. Access: 2020/10/09. (Portuguese).

Greggio Ferreira, João Vitor; Bastianik Nascimento, Vitor. Análise Da Distribuição De Bolsas E Auxílios À Pesquisa Do Programa Bioen-Fapesp No Estado De São Paulo. (2017). **REGRAD - Revista Eletrônica de Graduação do UNIVEM - ISSN 1984-7866**, [S.l.], v. 10, n. 01, p. 366 - 376, oct. 2017. ISSN 1984-7866. Disponível em: <https://revista.univem.edu.br/REGRAD/article/view/2074>. Access: 2020/10/27. (Portuguese).

Kantar. (2020). Mobility futures. Available in: https://www.tnsglobal.com/what-we-do/by-sector/automotive/mobilityfutures. Access: 10/Jul/2020.

Nakada, L. Y. K., & Urban, R. C. (2020). COVID-19 pandemic: Impacts on the air quality during the partial lockdown in São Paulo state, Brazil. Science of The Total Environment, 139087.

National Centers for Environmental Prediction/National Weather Service/NOAA/U.S. Department of Commerce. 2015, updated daily. *NCEP GDAS/FNL 0.25 Degree Global Tropospheric Analyses and Forecast Grids*. Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory. https://doi.org/10.5065/D65Q4T4Z. Access: 2020/06/01.

OpenStreetMap contributors. (2015) Planet dump. Retrieved from https://planet.openstreetmap.org.

Sao Paulo. (2015). Decreto 56.349, 21 August 2015. Available in: https://leismunicipais.com.br/a/sp/s/sao-paulo/decreto/2015/5634/56349/decreto-n-56349-2015-regulamenta-a-lei-n-15997-de-27-de-maio-de-2014-que-estabelece-a-politica-municipal-de-incentivo-ao-uso-de-carros-eletricos-ou-movidos-a-hidrogenio. Access: 10/Jul/2020. (Portuguese).

Sao Paulo. (2016). Decreto 56.834 , 24 February 2016. PlanMob/SP2025: Plano de Mobilidade de São Paulo. Available in: http://files.antp.org.br/2016/3/2/plano-mun-mob-urbana-sp-2015_1.pdf. Access: 10 Jul 2020. (Portuguese).

Sao Paulo. (2018). Lei 16.802, 17 January 2018. Available in: https://leismunicipais.com.br/a/sp/s/sao-paulo/lei-ordinaria/2018/1680/16802/lei-ordinaria-n-16802-2018-da-nova-redacao-ao-art-50-da-lei-n-14933-2009-que-dispoe-sobre-o-uso-de-fontes-motrizes-de-energia-menos-poluentes-e-menos-geradoras-de-gases-do-efeito-estufa-na-frota-de-transporte-coletivo-urbano-do-municipio-de-sao-paulo-e-da-outras-providencias. Access: 10/Jul/2020. (Portuguese).

Sao Paulo. (2019). Portaria 509, 24 September 2019. Available in: http://legislacao.prefeitura.sp.gov.br/leis/portaria-prefeito-pref-509-de-24-de-setembro-de-2019. Access: 10/Jul/2020. (Portuguese).

SMOKE, C. (2015). v3.7 User’s Manual. *Institute for the Environment, The University of North Carolina at Chapel Hill*. Available at: https://www.cmascenter.org/smoke/documentation/3.7/html/. Axxess: 2020/10/27.