Transportation Research Part D 58 (2018) 172–185

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

Road vehicle emission inventory of a Brazilian metropolitan area and insights for other emerging economies

Nara Angélica Policarpo[a], Carla Silva[b], Tâmara Freitas Aragão Lopes[c], Rinaldo dos Santos Araújo[a,c], Francisco Sales Ávila Cavalcante[a], Cira Souza Pitombo[d], Mona Lisa Moura de Oliveira[a,c,*]

[a] State University of Ceará, Av. Dr. Silas Munguba 1700, 60.714.903 Fortaleza, Brazil
[b] Instituto Dom Luiz, Faculdade de Ciências, Universidade de Lisboa, Portugal
[c] Technology Federal Institute of Ceará, Av. Treze de Maio 2081, 60.040-531 Fortaleza, Brazil
[d] Department of Transportation Engineering, São Carlos School of Engineering, University of São Paulo, Av. Trabalhador São-Carlense, 400, São Carlos, SP 13566-590, Brazil

ARTICLE INFO

Keywords:
Urban air pollution
Mobile combustion sources
Biofuels
Emission policies
Bus rapid transit

ABSTRACT

The vehicle fleet in the Ceará state has grown 180% over the last ten years. The growth of the resulting emissions is unknown in view of the expansion of this fleet in the greater Fortaleza Metropolitan Area (FMA). The largest fleet in the FMA is in the Fortaleza city itself, where flex fuel vehicles predominate (~30%). Flex fuel motorcycles increased significantly (greater than 800%) between 2010 and 2015. This paper aims to estimate the road vehicle emissions of carbon monoxide (CO), non-methane hydrocarbons (NMHC), aldehydes (RCHO), nitrogen oxides (NO_x), and particulate matter (PM) from the main road vehicle fleets of Fortaleza and its metropolitan area using a macrosimulation, bottom-up method, between 2010 and 2015. The results showed that road vehicle emissions of CO, NMHC and RCHO increased mainly by Otto cycle vehicles increase due to the introduction of flex fuel vehicles; however, the NO_x and PM emissions noticeable reduction is also a result of emission policies that seed the introduction of new technologies. In 2015, more than 70,000 tons of CO (21.2 ton/1000person), 8000 tons of NMHC (2.5 ton/1000person), 290 tons of RCHO (0.09 ton/1000person), 15,000 tons of NO_x (4.4 ton/1000person) and 600 tons of PM (0.2 ton/1000person) were emitted in the region under study. Comparing with other Brazilian regions, FMA emit higher levels of pollutants per inhabitant than the state of São Paulo and the state of Rio de Janeiro but lower levels than Porto Alegre city.

1. Introduction

Passenger and goods transport in Brazil is done mainly by road, and is highly dependent on fossil fuels. In 2014, the transport sector in Brazil consumed more than 60% of oil products (e.g. gasoline and diesel), and the road segment represents roughly 70% of the total energy consumption. Therefore, this sector is one of the main sources of urban air pollution, creating problems to the environment and to human health due to its combustion (MME, 2015; Morishita et al., 2006; Progiou and Ziomas, 2011; Silva et al., 2006; Souza et al., 2013; Zhang and Batterman, 2013). Ethanol biofuel blended with gasoline has been increasing since 2003 and since 2015 the gasoline sold has 27% bioethanol in it. The ethanol use reduces the oil dependence because it is produced by

* Corresponding author at: LACEEMA/CCT/UECE, State University of Ceará, Applied Physical Sciences, Av. Dr. Silas Munguba, 1700, Fortaleza, Ceara CP: 60.714.903, Brazil.
E-mail address: mona.lisa@uece.br (M.L.M.d. Oliveira).

https://doi.org/10.1016/j.trd.2017.12.004

endogenous sugar cane, and represents roughly 20% of the energy consumption in this road sector.

Fortaleza is the capital of the state of Ceará in northeastern Brazil, and has the seventh largest vehicle fleet in the country (387/1000 inhabitants) (DENATRAN, 2016). Currently, the Fortaleza Metropolitan Area (FMA), which includes 19 municipalities around the city of Fortaleza (including Fortaleza), is the sixth largest metropolitan area in Brazil (Cassiano et al., 2016; Cavalcante et al., 2009; IBGE, 2016). According to data from the Traffic State Department of Ceará (DETRAN-CE), the vehicle fleet of Ceará grew about 180% over the last ten years. In 2015, the FMA road vehicle fleet had more than one million vehicles, of which 75% were in Fortaleza itself (DETRAN-CE, 2017). This substantial increase in the road vehicle fleet has become an important source of urban air pollution in the region and, as well as result of this growth; there has been an increase in the number and size of traffic jams as well as ever increasing emissions of pollutants into the atmosphere. This scenario, which is common in large urban centers, is striving the need to carrying out studies concerning emissions (Cassiano et al., 2016a; Cavalcante et al., 2009; Schifter et al., 2005; Souza et al., 2013; Vivanco and Andrade, 2006), especially when considering atmospheric emission inventories as a management tool to improve the air quality of the local population. Besides, a monitoring network of air quality does not exist in FMA, and regarding data reported in literature information is scarce and limited to a couple of pollutants for the region (Cassiano et al., 2016b; Cavalcante et al., 2016; Rocha et al., 2016).

Several studies carried out in Brazil have pointed out a reduction of emissions with the gradual implementation of programs such as PROCONVE (Program for Control of Air Pollution by Automotive Vehicles) and PROMOT (Air Pollution Control Program for Motorcycles and Similar Vehicles) (CETESB, 2016; IBAMA, 2011; Réquia et al., 2015; Souza et al., 2013; Szwarcfiter et al., 2005; Ueda and Tomaz, 2011). Internationally, the guidelines of the EURO standards have, in particular, been a reference for the introduction of such regulatory policies worldwide (Cai and Xie, 2007; Jing et al., 2016; Tang et al., 2016). In Brazil, the current phases of PROCONVE/PROMOT are L6 for Otto cycle vehicles, P7 for Diesel cycle vehicles and M4 for motorcycles, as presented in the literature (DieselNet, 2016; IBAMA, 2011; MMA, 2013).

At present, Brazil follows the EURO V standard, which since January 2012 foresaw the implementation of the exhaust aftertreatment system, namely SCR – Selective Catalytic Reduction (Oliveira et al., 2011), for heavy diesel vehicles (i.e. buses and trucks). The technologies put into automotive vehicles, especially exhaust gas aftertreatment systems, and have been able to significantly reduce the emissions of polluting gases from vehicles over the years (Faiz, 1993). Gases such as carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2), particulate matter (PM), aldehydes (RCHO) and non-methane hydrocarbons (NMHC) are the main ones that have been reduced. However, these measures are still not sufficient. Consequently, road vehicle emission reductions are still being studied by the automotive industry, which is seeking technologies to lower emissions levels even further, since environmental standards are becoming increasingly restrictive (Aguiar et al., 2015; Elfasakhany, 2016; Lewtas, 2007; Ouyang et al., 2014; Shahir et al., 2015a, 2015b; Suarez-Bertoa et al., 2015; Szklo et al., 2005; Iodice et al., 2016; Zhu et al., 2014).

The first step to quantify the urban air pollution in cities is usually through a mobile source emissions inventory. Road vehicle emission inventories have been made in various large urban centers of Brazil (e.g. Porto Alegre – RS, Rio de Janeiro – RJ, São Paulo – SP, Vitória – ES) and around the world (e.g. Buenos Aires, London, Mexico City, New York, India, China, Norway). These measures have been taken by environmental agencies and other segments of the society in order to evaluate emissions and propose controls through public policies (Arriaga-Colina et al., 2004; CETESB, 2016; Cooper et al., 2014; D'Avignon et al., 2010; Fujita et al., 1992; López-Aparicio et al., 2017; MMA, 2013; Ozan et al., 2011; Schifter et al., 2005; Souza et al., 2013; Susilo et al., 2007; Venegas et al., 2011). An inventory of road vehicle emissions of air pollutants compiles fleet data over a given period in a given region. This has been shown to be a low-cost and fast-response tool that is extremely effective in assisting air quality models in urban centers (CETESB, 2016; D'Avignon et al., 2010; EPA, 2017; López-Aparicio et al., 2017; Pu et al., 2015), since detailed registration through monitoring networks is expensive (Réquia et al., 2015; Righi et al., 2013) and, according to Vormittag et al. (2014), there are only 252 monitoring stations in Brazil, which encompasses only 1.7% of Brazilian cities. In addition, estimated road vehicle emissions from inventories can be used as the input to a database for pollutant dispersion models (Jing et al., 2016; Tang et al., 2016) and, therefore, air quality forecasts (He et al., 2016).

There are two usual methodological approaches: the bottom-up (BU) and the top-down (TD). The former refers to using emission factors per vehicle category in a specific region/city and eventually aggregated to give a National perspective and the latter usually refers to spatially aggregated data (Nationally wise) disaggregated to provide insight on a specific region/city. This is also used when looking to the energy consumption methodologies (Horowitz and Bertoldi, 2015).

An extensive literature recommends the use of the bottom-up method used by the United States Environmental Protection Agency (EPA, 1994; Singer, 1998; Perugu et al., 2017), which has been shown to be effective in estimating vehicle emissions (Colvile et al., 2001; Cook et al., 2006; Pu et al., 2015; Righi et al., 2013; Wang et al., 2009; Zhu et al., 2014). This method uses data of the local fleet in circulation, combined with pollutant emission factors and annual mileage of vehicle (CETESB, 2016; MMA, 2013; Souza et al., 2013; Teixeira et al., 2008; Wang et al., 2009). Emission factors are one of the complex parameters that are acquired through models validated for emission measurements and driving cycle tests, and include vehicle characteristics, vehicle classification and age, fuel type, as well as emission control policies among other characteristics (Cassiano et al., 2016a; Cook et al., 2006; Gallus et al., 2016; Jing et al., 2016; Lawrence et al. 2016; Oduro et al., 2016; Pu et al., 2015; Schifter et al., 2005; Song et al., 2016). In addition, the emission factor is an indicator of emission control coming from the technological evolution of motor vehicles (CETESB, 2016). In the last years, emission factors are extensively acquired through the COPERT (COmputer Program to calculate Emissions from Road Transport) (Jing et al., 2016; Song et al., 2016). Based on Tier 3 approach (EEA, 2016), COPERT is the most complete bottom-up method since it accounts all type of exhaust and non-exhaust road vehicle emissions such as hot-running, cold-start, urban, rural, and highway emissions.

In China, for example, Tang et al. (2016) published estimates for the years 2006–2010, as the total number of vehicles increased