Science of the Total Environment 586 (2017) 512–521

Contents lists available at ScienceDirect

Science of the Total Environment

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

Vehicle emission trends in China's Guangdong Province from 1994 to 2014

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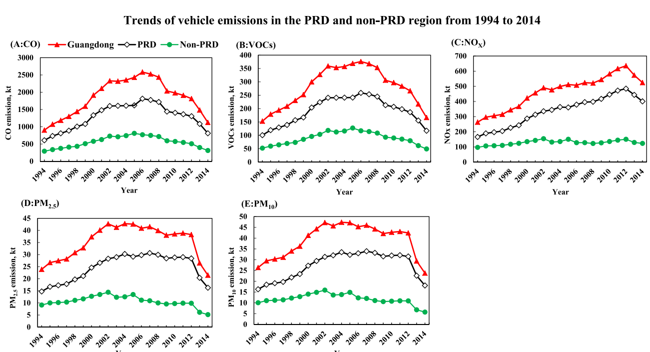
HIGHLIGHTS

- Multiyear inventories of vehicular emissions from 1994 to 2014 in Guangdong province were estimated.
- The amount of vehicle emissions firstly increased and then decreased around 2002.
- The pollutants emissions in the PRD region were 2.4-3.3 times than in the non-PRD region.
- The pollutants emissions variation has a good agreement with the population of yellow-label vehicles.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 27 October 2016
Received in revised form 18 January 2017
Accepted 31 January 2017
Available online 12 February 2017

Editor: D. Barcelo

Keywords:
Vehicle emissions
Multi-year inventories trends
PRD and non-PRD region
GDP

ABSTRACT

Exploring vehicle emission trends within and outside the Pearl River Delta (PRD) region during a long period was scientific and practical, for the economic rapid unbalanced development, continuous implements of severe reducing vehicle emissions measures in Guangdong province. Multi-year inventories of vehicle emissions from 1994 to 2014 were estimated based on the emissions factors of different emissions standards and vehicle kilometers travelled for all types of vehicles. The trends and characteristics of the emissions of carbon monoxide (CO), volatile organic compounds (VOCs), nitrogen oxides (NO_x), fine particulate matter ($PM_{2.5}$) and course particulate matter (PM_{10}) were then analyzed within and outside the PRD region. In the above two regions, the total amount of the five pollutant emissions varied greatly with gross domestic product (GDP) from 1994 to 2014, showing the overall performance of the first increasing up to 1.6–3.0 times before 2002, and then decreasing. However, the five pollutant emissions in the PRD region were 2.4–3.3 times more than in the non-PRD region. In both regions, light passenger cars and motorcycles were the main contributors to CO and VOC emissions (65%–80%), and heavy duty trucks and passenger cars were the main contributors to NO_x, $PM_{2.5}$ and PM_{10} emissions (around 42%–50%). Moreover, compared to CO and VOCs emissions, the changes in the contribution of every vehicles type to NO_x, $PM_{2.5}$ and PM_{10} emissions were more obvious, and coincided with the implementation time of emission and fuel standards in the non-PRD region. It was noted that CO and VOC emission variations was correlated closely with the population of yellow-label light passenger cars and motorcycles, whereas those of NO_x and $PM_{2.5}$ was coincided that of yellow-label heavy passenger cars and trucks.

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http://dx.doi.org/10.1016/j.scitotenv.2017.01.215
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1. Introduction

Vehicles have in recent years contributed significantly to global, regional and local emissions of carbon monoxide (CO), hydrocarbons (HCs), nitrogen oxides (NO_x), and particulate matter (PM) (Lang et al., 2014; Lu et al., 2013; McDonald et al., 2012; Zhang et al., 2009), which has been an important influence on air quality. For example, vehicles are found to account for approximately 64.1%, 57%, 11% and 35% of the atmospheric concentrations of NO_x, non-methane VOCs, precursor organic compounds and black carbon (BC) in urban Beijing (Cheng et al., 2013; Song et al., 2007). The adverse impacts of vehicle emissions on human health and climate change represent another issue attracting wide attention in recent years (Shindell et al., 2011; Uherek et al., 2010; Gulia et al., 2015; Sonawane et al., 2012). So, it is of great scientific importance to develop vehicle emission inventories and analyze the vehicle emission trends for a long period, for developing and evaluating effective air pollution control and mitigation strategies.

Estimations of vehicle emissions in China have been mostly based on a range of methods put forward by international researchers. For example, Klimont et al. (2009) calculated the NO_x, BC and organic carbon (OC) emissions from road transport in China in 2000 and 2005, and projected the results to give estimates for 2011, 2020 and 2030. Cai and Xie (2007) calculated the vehicle emissions in China for the period 1980–2005, while the emissions for the three most developed regions of China—Beijing–Tianjin–Hebei (BTH), the Yangtze River Delta (YRD) and the Pearl River Delta (PRD)—were calculated by Lang et al. (2012), Fu et al. (2013) and Lu et al. (2013), respectively. Similarly, Yao et al. (2006) and Wang et al. (2010) established the vehicle emissions of CO, VOCs, NO_x and coarse PM (PM_{10}) for Beijing, Shanghai and Guangzhou, analyzing the trends from 1999 to 2005. Huo et al. (2015) calculated the average emissions factors (units: g/km) in China for CO, VOCs, NO_x and fine PM ($PM_{2.5}$) for the period between 2000 and 2012. Liu et al. (2015) provided four kinds of basic emissions factors for VOCs: diurnal, hot soak, permeation, and refueling. Wu et al. (2016) assessed China's first 15-year (1998–2013) efforts in controlling vehicle emissions, based on national-scale total annual vehicle emission data for HCs, CO, NO_x and $PM_{2.5}$.

A limitation of the above-mentioned studies is that most were carried out either over a short time-span, in a single year or decade, with many before 2010, or in a limited region, with some focused on local or developed areas with only basic traffic data, such as the BTH, YRD or PRD region. Furthermore, for Guangdong Province, which includes the PRD region and 12 other cities in what we term as the "non-PRD region", with the largest and fastest growing economy in China during the past 20 years (HKTDC, 2015), the research of vehicle emissions has been lacking (the last major research was before 2006) and focused on the short-term. Combined with the continuous and rapid growth of the vehicle population, and the progressive implementation of policies and measures to reduce vehicle emissions (e.g., implementing emissions standards from China I to China V (Equal to Euro vehicle emission standard.)) and eliminating yellow-label vehicles (High Emitors, which are gasoline vehicles before China I emission standard or diesel vehicles before China III emission standard.) during the last 20 years, there is an urgent need to estimate and analyze the vehicle emissions and their characteristics of change in this part of China.

In the above context, and taking into account the uneven development of Guangdong Province between the 9 cities in the PRD region and the 12 others in the non-PRD region, the present study set out to estimate the vehicle emissions of CO, VOCs, NO_x, $PM_{2.5}$ and PM_{10} in Guangdong Province from 1994 to 2014. Then, distinguishing between the PRD and non-PRD region, the respective differences in the vehicle emission trends and the reasons were analyzed.

2. Study area

Guangdong Province is an important political, economic and cultural center in southern China. It is one of the most economically vibrant provinces of China, covering 1.87% of the Chinese land territory while accounting for 10.7% of the total national gross domestic product (GDP) in 2014. The population in Guangdong Province was 107.2 million in 2014, accounting for 7.84% of the Chinese population (NBS, 2015). At the same time, the road transport is also well-developed; the car population was 13.26 million in 2014, accounting for 9.17% of the total number of vehicles in China. The length of operational motorway reached 212,100 km, and that of expressways was 6280 km, making it ranked first in China in terms of national expressway mileage (PGGDP, 2014).

The province includes 9 cities in the PRD region and 12 cities in the non-PRD region, as shown in Fig. 1. During the past 20 years, although GDP has varied greatly, the vehicle population in both the PRD region and non-PRD region has grown rapidly, albeit at different rates of between two and fivefold (Ma et al., 2015). Meanwhile, due to more stringent implementation of vehicle control policies and measures in the PRD region compared with the non-PRD region, a large number of high-emitting vehicles have transferred to the non-PRD region through second-hand transactions. So, the above factors have likely led to differences in vehicle emissions between the two regions (Huo et al., 2012a). Additionally, motor-vehicle-related air pollution is a key problem in the PRD region, resulting first in the emergence of $PM_{2.5}$ pollution from 1995 to 2010, and now O_3 and NO_x pollution has also become another major concern (Kim et al., 2012). So, while the vehicle emission characteristics in the PRD region and non-PRD region are specific to this particular area, understanding the trends of vehicle emissions in recent decades could nevertheless be used as a reference for other provinces/cities in China that implemented regulatory policies at different times.

3. Methodology

Vehicle emissions factors are key parameters when estimating emissions inventories, and some studies in this regard have been conducted based on the COPERT model or IVE model (Wang et al., 2010; Yao et al., 2006). Based on comparable research to the present study, the localized vehicle emissions factors were calculated using the various emissions standards in every city of Guangdong Province from 1994 to 2014, according to the National Technical Guidelines of the Air Pollutant Emissions Inventory for Road Motor Vehicles, issued in 2014. Then, combined with vehicle population and vehicle kilometers travelled (VKT) data, the emissions inventory was estimated.

3.1. Emissions calculation method

Vehicle emissions of CO, VOCs, $PM_{2.5}$, NO_x and PM_{10} in every city in the PRD region and non-PRD region were estimated using the following equation:

$$Q_{mijkc} = EF_{mijk} \times M_{ik} \times P_{ijkc} \quad (1)$$

where m, i, j, k and c represent the pollutant type, vehicle type, emissions standard, year, and city, respectively. Q_{mijkc} represents the pollutant m's emissions from vehicle type i with j emissions standard in year k for city c, in units of 10^4t. EF_{mijk} represents the pollutant m's emissions factors of vehicle type i with j emissions standard in year k, in units of g/(km·veh). M_{ik} represents the VKT of vehicle type i in year k, in units of km/a. And P_{ijkc} represents the vehicle population of vehicle type i with j emissions standard in year k in city c, in units veh.

After calculating the emissions of different pollutants in every city, adding every city's emissions in the PRD region and non-PRD region

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