JOURNAL OF ENVIRONMENTAL SCIENCES 51 (2017) 75–87

Available online at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/jes

JES JOURNAL OF ENVIRONMENTAL SCIENCES

www.jesc.ac.cn

City-specific vehicle emission control strategies to achieve stringent emission reduction targets in China's Yangtze River Delta region

Shaojun Zhang[1], *Ye Wu*[2,3,*], *Bin Zhao*[4], *Xiaomeng Wu*[2], *Jiawei Shu*[2], *Jiming Hao*[2,3]

1. *University of Michigan, Department of Mechanical Engineering, Ann Arbor, MI 48109, USA*
2. *Tsinghua University, State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Beijing 100084, China*
3. *State Environmental Protection Key Laboratory of Sources and Control of Air Pollution Complex, Beijing 100084, China*
4. *Joint Institute for Regional Earth System Science and Engineering, Department of Atmospheric and Oceanic Sciences, University of California, Los Angeles, California 90095, USA*

ARTICLE INFO

Article history:
Received 13 January 2016
Revised 30 May 2016
Accepted 1 June 2016
Available online 18 November 2016

Keywords:
Vehicle
Emission control
Scenario
Yangtze River Delta

ABSTRACT

The Yangtze River Delta (YRD) region is one of the most prosperous and densely populated regions in China and is facing tremendous pressure to mitigate vehicle emissions and improve air quality. Our assessment has revealed that mitigating vehicle emissions of NOx would be more difficult than reducing the emissions of other major vehicular pollutants (*e.g.*, CO, HC and $PM_{2.5}$) in the YRD region. Even in Shanghai, where the emission control implemented are more stringent than in Jiangsu and Zhejiang, we observed little to no reduction in NOx emissions from 2000 to 2010. Emission–reduction targets for HC, NOx and $PM_{2.5}$ are determined using a response surface modeling tool for better air quality. We design city-specific emission control strategies for three vehicle-populated cities in the YRD region: Shanghai and Nanjing and Wuxi in Jiangsu. Our results indicate that even if stringent emission control consisting of the Euro 6/VI standards, the limitation of vehicle population and usage, and the scrappage of older vehicles is applied, Nanjing and Wuxi will not be able to meet the NOx emissions target by 2020. Therefore, additional control measures are proposed for Nanjing and Wuxi to further mitigate NOx emissions from heavy-duty diesel vehicles.

Introduction

China has undergone extraordinary economic growth over the past three decades. However, this growth has been accompanied by a surge in energy consumption and serious air pollution (NBSC, 2014; Xing et al., 2011a; Wang and Hao, 2012). For example, extremely high pollution levels of major pollutants (*e.g.*, fine particulate matter less than 2.5 μm in diameter, $PM_{2.5}$, and nitrogen dioxide, NO_2) were recently observed over the coastal areas of East China both *in situ* and from space (Wang et al., 2011a; Cheng et al., 2013; Richter et al., 2005), and these high pollutant levels have negatively influenced public health, climate and agriculture (Shindell et al., 2011; Tong et al., 2012, 2015). For many megacities in these areas (*e.g.*, Beijing, Shanghai, and Guangzhou), the air pollution patterns have clearly shifted from coal-based pollution to a mixture of coal- and vehicle-based pollution, and on-road vehicles are considered to be one of the most important sources of airborne $PM_{2.5}$ (Wu et al., 2011; China

* *Corresponding author*. E-mail: ywu@tsinghua.edu.cn (Ye Wu).

http://dx.doi.org/10.1016/j.jes.2016.06.038
1001-0742/

Daily, 2015). Furthermore, recent studies have indicated that vehicular emissions of nitrogen oxides (NOx) and hydrocarbons (HC) play a role in the formation of secondary inorganic and organic aerosols during episodes of severe haze, which might be underestimated by existing atmospheric models (He et al., 2014; Guo et al., 2014; Robinson et al., 2007; Gordon et al., 2014).

In response to regional and urban air pollution, China's Central Government has released a series of policies and regulations to reduce urban air pollution. For instance, China's government set a 10% mitigation target for national anthropogenic NOx emissions during the period of the "Twelfth Five Year Plan" (12th FYP, *i.e.*, 2011–2015) (Wu et al., 2012a). In 2012, China's State Council approved the National Ambient Air Quality Standard (NAAQS) Amendment (MEP and AQSIQ, 2012). This legislation tightened the concentration limits for nitrogen dioxide (NO_2) and inhalable particulate matter with diameters less than 10 μm (PM_{10}) and also added limits on annual and 24-hr average $PM_{2.5}$ concentrations and the 8-hr average ozone (O_3) concentration, as recommended by the World Health Organization's interim targets (see the Grade II limits for regular areas in Table S1). In 2013, China's State Council released its Action Plan for Air Pollution and Control for improving overall air quality across the nation and reducing the number of severely polluted days by 2017 (State Council, 2013). Additionally, certain megacities, such as Beijing and Shanghai, also published city-level Clean Air Action Plans 2013–2017, which contain stringent and comprehensive emission control measures to be implemented in the near future (Beijing Municipal Government, 2013; Shanghai Municipal Government, 2013; Zhang et al., 2014a; Wu et al., 2017). More recently, $PM_{2.5}$ source apportionment studies in nine major cities have revealed that on-road vehicle emissions have become the most significant local source of ambient $PM_{2.5}$ concentrations in five cities (Beijing, Shanghai, Guangzhou, Shenzhen and Hangzhou), where the total vehicle population has exceeded 2.5 million (MEP, 2015). Therefore, for municipal policy makers, the priority of controlling vehicles to improve air quality has become increasingly significant, particularly in relatively more motorized cities in East China.

The Yangtze River Delta (YRD) region, geographically consisting of Shanghai Municipality, Jiangsu Province and Zhejiang Province, is one of the most prosperous regions in China and is also one of the most densely populated sectors adjacent to metropolitan areas worldwide. Although its geographical area constitutes only 2.2% of China's total area, the YRD region in 2013 contained 12% of the resident population and 15% of the vehicle stock (not including motorcycles and rural vehicles), contributing 20% of China's gross domestic product (GDP) (NBSC, 2014). However, the YRD region is currently facing great challenges to the improvement of air quality and must accelerate its future vehicle emission control policies and practices to maintain its social development and urbanization.

It should be noted that most studies regarding future vehicle emission trends in China primarily focused emission inventories (more about CO_2) at the national or provincial levels, and lacked clear associations with the improvement of air quality (Zhang et al., 2014a; Huo et al., 2012, 2014; Saikawa et al., 2011). In reality, due to the highly spatial heterogeneity in China, the emission control requirements at a broader level (*e.g.*, the national level required by Ministry of Environmental Protection) are usually more vague and less stringent than those actually adopted in more motorized cities (*e.g.*, Beijing, Shanghai). In this study, we first evaluate the historic trends in total vehicle emissions of the YRD region and highlight the many difficulties from historical and international perspectives. Second, stringent reduction targets for vehicular emissions of HC, NOx and $PM_{2.5}$ are proposed. We investigate the local features of these three representative cities (*e.g.*, Shanghai, Nanjing and Wuxi) and design city-specific plans for emission control strategies and measures through 2020. This paper provides policy-makers with a prospective understanding of future vehicle emission controls in China for improving urban air quality, which can only be achieved through great effort.

1. Methods and data

1.1. Trends in vehicle population, annual mileage and fleet configuration

During 2000–2010, the total vehicle population in the YRD increased from 8.7 million to 27.4 million, primarily because of the surge in light-duty passenger vehicles (LDPVs) (see Fig. S1) (NBSC, 2014). Previous studies have reported that the Gompertz function is a reasonable model for relating the LDPV ownership rate to economic development (Wu et al., 2012b). Therefore, we predict the future trends in the LDPV populations of Nanjing and Wuxi using city-specific fitted Gompertz functions (see Fig. S2) based on the historic census data for these cities. Notably, Shanghai has a significantly lower LDPV ownership rate than other cities in China's three developed regions (see Table S2) due to its long history of restricting LDPV purchase (*i.e.*, license control policies), which began in 1994 (Hao et al., 2011). For other vehicle classifications, we predicted their future populations based on historical trends and several relevant policies. For example, a substantial surge in truck stocks in the YRD region occurred in approximately 2010 because of a package of economic stimulation measures that began in late 2008. After 2011, the role of those policies in the truck market became less significant, and the shift from light-duty and medium-duty trucks (*i.e.*, LDTs and MDTs) to heavy-duty trucks (HDTs) is clearly observed. In addition, use restrictions for motorcycles have been adopted in several cities (*e.g.*, Nanjing and Wuxi) within the YRD region since 2000, leading to a decline in the motorcycle population since 2007. The projected total vehicle population of Shanghai, Nanjing and Wuxi was predicted to increase to 3.6 million, 2.4 million, and 1.9 million, respectively, under the business-as-usual (BAU) and moderate scenarios (see Fig. 1, and refer to Table 3 for the definition of scenarios). In particular, the share of LDPVs is projected to increase to 73% in Shanghai, 82% in Wuxi and 88% in Nanjing, whereas the motorcycle population is projected to decline.

In this study, we estimate the annual vehicle kilometers traveled (VKT) for each fleet in the YRD based on previous surveys in China (Zhang et al., 2013, 2014a) and recently collected vehicle mileage data from Nanjing. Table 1 provides the estimated fleet-average annual VKT for major