Science of the Total Environment 599–600 (2017) 944–951

Contents lists available at ScienceDirect

Science of the Total Environment

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

Modeling carbon emissions from urban traffic system using mobile monitoring

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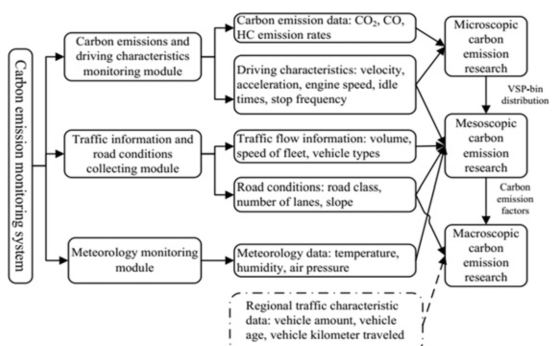
HIGHLIGHTS

- Constructed an urban carbon emission monitoring system using **mobile monitors** and collected traffic characteristics and meteorological data.
- Identified the traffic carbon emission at **microscopic, mesoscopic and macroscopic levels, and assessed t**he major influenced factors.
- VSP-bin is categorized into: **idle, low velocity, medium velocity and high velocity**, so as to figure out the proportion of idling condition for MOVES.
- With the final carbon emission factors calculated by MOVES, **arterial traffic** was identified to generate the major carbon emissions among the urban road system.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 28 March 2017
Received in revised form 24 April 2017
Accepted 25 April 2017
Available online 11 May 2017

Editor: D. Barcelo

Keywords:
Urban traffic
Carbon emissions
Mobile monitoring
MOVES
Emission factor

ABSTRACT

Comprehensive analyses of urban traffic carbon emissions are critical in achieving low-carbon transportation. This paper started from the architecture design of a carbon emission mobile monitoring system using multiple sets of equipment and collected the corresponding data about traffic flow, meteorological conditions, vehicular carbon emissions and driving characteristics on typical roads in Shanghai and Wuxi, Jiangsu province. Based on these data, the emission model MOVES was calibrated and used with various sensitivity and correlation evaluation indices to analyze the traffic carbon emissions at microscopic, mesoscopic and macroscopic levels, respectively. The major factors that influence urban traffic carbon emissions were investigated, so that emission factors of CO, CO_2 and HC were calculated by taking representative passenger cars as a case study. As a result, the urban traffic carbon emissions were assessed quantitatively, and the total amounts of CO, CO_2 and HC emission from passenger cars in Shanghai were estimated as 76.95 kt, 8271.91 kt, and 2.13 kt, respectively. Arterial roads were found as the primary line source, accounting for 50.49% carbon emissions. In additional to the overall major factors identified, the mobile monitoring system and carbon emission quantification method proposed in this study are of rather guiding significance for the further urban low-carbon transportation development.

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http://dx.doi.org/10.1016/j.scitotenv.2017.04.186
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1. Introduction

The rapid urbanization, motorization, and economic growth in China over the past ten years have resulted in severe environmental deterioration, in particular, the sharp growth of traffic emissions. World Energy Outlook predicted that urban traffic-related carbon emission would increase at an annual rate of 1.7% from 2010 to 2030, while the annual growth rates of traffic-related carbon emissions in developing countries and moderately developed countries, are projected at 3.4% and 4.2%, respectively (Aleklett et al., 2010). When it comes to Shanghai, mobile source emissions are responsible for approximately 78% of carbon monoxide (CO) and 83% of hydrocarbons (HC) according to the statistics (Wang et al., 2008a). To attain an international climate change agreement at Copenhagen or beyond, the Chinese government announced the long-term pledge to reduce carbon emissions by 40–45% by 2020 relative to the standard in 2005 (Zhang, 2011). To achieve this ambitious goal, understanding traffic-related carbon emissions at different spatial and temporal scales is essential, so that to stipulate effective policies and strategies for carbon emission management. To this end, comprehensive investigations utilizing efficient tools and data sources are crucial to avoid high uncertainties or mistakes brought by assumptions or roughly qualitative intuitions.

During the carbon emission monitoring, conventional studies generally relied on engine dynamometer testing and remote sensing (Franco et al., 2013), in which the emission rates were measured by simulating driving cycle. Pelkmans and Debal (2006) used new European driving cycle (NEDC) to measure CO, CO_2, HC emissions of various light-duty gasoline vehicles in engine dynamometer, revealing the connection between emissions and driving characteristics. However, the measurement generally takes longer duration and is not consistent with real-world driving conditions (Smit et al., 2010). On the contrary, the on-road remote sensing system which generally has comparative high sampling rate and rapid detecting speed has been used in many cities, such as Los Angeles and Mexico City (Burns et al., 2012). Guo et al. (2007a,b) used the remote sensing equipment to collect both emissions and driving characteristics of real-world vehicle fleet, and generated travel-based emission inventories for Hangzhou, China. Nevertheless, the remote sensing system doesn't work appropriately while monitoring heavy-polluting vehicles and the non-uniform height of tailpipes may also introduce errors. Consequently, portable emissions measurement systems (PEMS) for onboard measurement of exhaust emissions were introduced (Liu et al., 2009). Second-by-second data from PEMS allow quantifying the representative cycles and corresponding emissions (DeFries et al., 2014), which are useful in developing emission inventories for a wide range of vehicle types, so as to obtain reliable and accurate emission measurements. Kousoulidou et al. (2013) used PEMS to collect emissions from both gasoline and diesel vehicles, and validate the corresponding emission factors in COPERT model (COmputer Programme to calculate Emissions from Road Transport). Unfortunately, the majority of these existing studies failed to form an integrated monitoring system to collect carbon emissions and the related factors simultaneously.

For investigations on traffic-related carbon emissions, the majority of existing studies have focused on the principle of carbon emissions within fixed time-space scale.

At microscopic level, recent studies mainly focused on revealing the relationship between carbon emissions and driving characteristics based on second-by-second data. Abou-Senna and Radwan (2013) used VISSIM (Verkehr In Städten-SIMulationsmodell in German) and MOVES (MOtor Vehicle Emission Simulator) to investigate the effect of major parameters on CO_2 emissions. The results indicate that speed generally has significant impact on CO_2 emissions when the detailed microscopic vehicular operations of acceleration and deceleration are considered. Initially developed by Jimenez (1998), vehicle specific power (VSP) is reported as the instantaneous power per unit mass of the vehicle. The definition has then been used in activity-based modes and to quantify emission variation of various operational states, including idle, acceleration, cruise, and deceleration (Coelho et al., 2009). Ritner et al. (2013) accounted for acceleration and deceleration carbon emissions in urban intersections, and found that acceleration emissions were in an order of magnitude larger than cruise emissions, while deceleration emissions are smaller than cruise emissions. Furthermore, Song et al. (2013) proved that VSP distribution is an effective explanatory parameter of carbon emissions.

At mesoscopic level, various emission models were proposed to evaluate the carbon emissions on road networks (Kota et al., 2012). The models were mainly divided into two groups. Driving cycle based models, such as MOBILE and EMFAC (EMission FACtors), rely mainly on speed distribution, while operating mode based models, including IVE (International Vehicle Emission) and MOVES, depend on VSP distribution. In the United States, the existing official model of Environmental Protection Agency (EPA) for estimating vehicular emissions is MOVES, which quantifies emission as a function of the vehicular operating mode. Fujita et al. (2012) conducted an on-road mobile source emission survey, and then compared to MOVES2010, MOBILE6.2 and EMFAC2007. An overall increase in motor vehicle nonmethane hydrocarbon (NMHC) emissions was identified during hot days that are not fully accounted for by the emission models. Moreover, the ability of EPA's MOVES model to simulate varying vehicle operating modes places increased importance on the choice of operating modes to evaluate project-level emissions. Liu et al. (2013) used MOVES for emission factor estimation and concluded that the regional vehicle operating characteristics should be considered.

At macroscopic level, emission models are usually used for large-scale analysis, aiming to estimate the total amount of emission and establish regional emission inventories. Although models e.g. MOBILE, COPERT and IVE are widely used, they are unfortunately designed to quantify emissions in United States or European countries. Meanwhile, empirical models provided in the previous research mainly focused on the particularly study areas. When applied in other areas, different vehicular operating conditions and emission performances may lead to significant biases. Despite the above models, Inter-governmental Panel on Climate Change (IPCC) offered two emission quantification models at macroscopic level, namely the top-down model and the bottom-up model (Eicker et al., 2008). Both models were used to set up traffic-related emission inventories in seven Chilean cities, analyzing the applicable condition of each model, respectively (Eicker et al., 2008). It was found that the top-down model calculates the total carbon emission amount based on fuel consumption, which has rather high accuracy but is unable to quantify subdivision carbon emission. On the contrary, the bottom-up model calculates carbon emissions based on vehicle-mile of travel (VMT), which is able to quantify subdivision carbon emission and the computational accuracy depends on a variety of emission factors.

The purpose of this study is to propose a comprehensive mobile monitoring model and calculate carbon emissions at microscopic, mesoscopic and macroscopic levels, respectively based on the mobile monitoring data. The remainder of the paper is organized as follows. Section 2 constructs a carbon monitoring system to collect vehicular emissions, as well as the related traffic flow, meteorological conditions and driving characteristics. Then, Section 3 investigated traffic carbon emissions from hierarchical aspects, including microscopic, mesoscopic and macroscopic levels, thus to ascertain the principle relationship with different vehicular operation parameters, travel conditions for particular road or segment, and the overall road transportation system. Finally, conclusions and recommendations for future work are provided in Section 4.

2. Experiment design and data collection

To collect carbon emissions and the related factors under different conditions, traffic carbon emission mobile monitoring system (TCEMMS)

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