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Towards a low carbon transition of urban public transport in megacities: A case study of Shenzhen, China

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ABSTRACT

The urgent need to develop low carbon urban transport systems particularly in Asian megacities is facing the significant challenge of growing motorization following population increase and economic development. Sustainable urban public transport (UPT) plays a crucial role to fulfil the ambitious targets on carbon emission reduction. In this study, life cycle assessment was employed to quantify the environmental impacts (measured by carbon emissions) of UPT systems (including bus and subway) in Shenzhen, a leading megacity in South China, and then to examine corresponding carbon intensity reduction potentials. Results showed that the total carbon emissions from UPT in Shenzhen have increased rapidly from 0.70 Mt in 2005 to 1.74 Mt in 2015 due to the fast growth of the volume of transport turnover. However, current low-carbon UPT mode has only reduced 0.21 Mt CO_2 e (cumulative value, from 2005 to 2015), and thus could not contribute proportionally to the city's overall emission reduction target. Three advanced scenarios (from conservative to optimistic) were further simulated to estimate carbon emissions and their intensity reduction potentials over the next 15 years (2016–2030). Compared to the business-as-usual scenario, all these three low-carbon transition scenarios could significantly mitigate the rapid growth of carbon emissions and consequently help achieve Shenzhen's carbon intensity reduction goal by 2030 (60%, compared to 2005 level). These findings could not only inform evidence-based policy making to facilitate the low-carbon transition of the urban transport sector in Shenzhen, but also shed light on sustainable urban transition in other megacities.

1. Introduction

Transport, by far the second largest sector in terms of global carbon emissions, accounted for around 23% of the total carbon emissions from fuel combustion in 2014 (International Energy Agency (IEA, 2016). Urban public transport (UPT) is one of the major contributors to those global carbon emissions. In 2016, the Chinese government submitted its Intended Nationally Determined Contributions (INDC) to United Nations which stipulates that China aims to reach its peak of carbon emissions around 2030 at the latest and to reduce carbon dioxide emissions per unit of GDP by 60%–65% compared to the 2005 level (National Development and Reform Commission of China (NDRC, 2015). To fulfil these ambitious commitments, it is imperative to implement sustainable transport so that greater carbon efficiency can be achieved at the city level (Zhao et al., 2016). Meanwhile, such a transition to a low-carbon economy would also be important for the improvement of air quality (Andrews-Speed, 2012). Therefore, it is of pressing importance to understand the efficiency of the current transport system and its role in sustainability transition.

As one of China's fast-growing cities, Shenzhen is facing significant environmental challenges similar to other megacities in China due to the rapid expansion of the transport sector. Specifically, public buses have experienced a rapid growth in Shenzhen, from 8403 in 2005 to 15,120 in 2015 ("Yearbook of Transportation & Communications" in Shenzhen) (Transport Commission of Shenzhen Municipality (TCSM, 2016a). This is mainly due to the urban population growth (from 8.3 in 2005 to 11.4 million in 2015) and associated demand for transportation (Statistics Bureau of Shenzhen (SBS, 2016). Meanwhile, Shenzhen has made significant investment to extend the length of its subway lines, from 22 km in 2005 to 177 km in 2015. By the end of 2016, a total of 8

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lines and 198 stations have been constructed and put into operation, with a total mileage of 284 km. Although public transport is one of the most effective means for transportation, its fast growth leads also to substantial challenges such as air quality, energy security, and public health impacts (e.g., Wu et al., 2012; Zhang et al., 2013; Du et al., 2012). According to the Shenzhen Municipal Committee on Human Settlements, vehicles are the most significant contributor to haze events (about 41%) in Shenzhen. Accordingly, more attention has been paid to energy saving and carbon emissions reduction of the urban transport systems, and since 2008, Shenzhen has become one of the first batches of national pilot cities for alternative fuel vehicles (see Table S1, Supplementary Material). For instance, Shenzhen has launched a program for a large-scale application of hybrid or electric pubic buses (accounts for 43% in 2015 and 100% in 2017 in total). However, the effect of these new types of vehicles on emission reduction has not yet been investigated.

A number of previous studies have discussed the environmental impacts of public transport systems at various scales (Zheng et al., 2012; Guo et al., 2014; Duan et al., 2015; Zhang et al., 2015; Nyhan et al., 2016). In particular, Duan et al. (2016) examined the carbon emissions from the transport system in Shenzhen and found that the carbon emissions of UPT accounted for around 24% (UPT-subway: 0.9%, UPT-bus: 21.6%, UPT-taxi: 1.1%) of the total carbon emissions of vehicles, of which subway and urban bus transport accounted for more than 95%. Zhao et al. (2016) predicted the low carbon future of Shenzhen's urban passenger transport system from 2014 to 2050. However, neither of these two studies provided a detailed analysis of future carbon emissions from UPT from 2005 and 2030 and corresponding reduction potentials.

A few other studies introduced advanced management methods (e.g., Fan and Lei, 2016; Peng et al., 2015; Yang et al., 2016) or used vehicles as a functional unit (e.g., Faria et al., 2013; Pero et al., 2015; Li et al., 2016; Lajunen and Lipman, 2016) for the analysis of the economic and environmental impacts of urban transport systems. For example, Li et al. (2016) estimated the greenhouse gas (GHG) emissions of urban rail transit systems in Shanghai using a full life cycle assessment (LCA). Lajunen and Lipman (2016) conducted the life cycle cost analysis and calculated carbon dioxide emissions of diesel, natural gas, hybrid electric, fuel cell hybrid, and electric transit buses. The comparison of environmental impacts of different types of vehicles is also a research focus in the literature (e.g., Ma et al., 2012; Onat et al., 2015; Belboom et al., 2016). For example, Onat et al. (2015) compared conventional, hybrid, plug-in hybrid, and electric vehicles options across 50 states in the United States. However, the effectiveness of current measures on energy saving and emission reduction potentials of the UPT system is still largely overlooked (e.g., Duan et al., 2016; Zhang et al., 2014; Doll and Balaban, 2013; de Andrade and Márcio de Almeida, 2016). Most of the existing studies that evaluated this (Menezes et al., 2017) were based on simulation and lack quantitative analysis of the actual data.

In this paper, based on a streamlined LCA method (Olivetti et al., 2013a,b) and scenario analysis, we aim to provide a first comprehensive estimate of Shenzhen's UPT energy consumption and carbon emissions from 2005 to 2015. Actual data were obtained from related government departments and field survey in Shenzhen. Then, we investigated the role of various transport modes in achieving a low carbon transition, identified the major contributors via sensitivity analysis, and evaluated the effectiveness or 'achievements' of different emission reduction measures via scenario analysis.

2. Methodology

2.1. Scope and system boundary

This study addresses the UPT system, i.e. urban bus transport system and subway transport system. Taxis were not included because: (i) they contribute only about 5% to the total carbon emissions of the public transport (Duan et al., 2016); (ii) they are not mass transit mode like buses and subways; and (iii) they have very different set of policies, markets, and regulatory issues.

Further, the boundary of this study involves only the operation stage and is also restricted to the area of Shenzhen. The operation stage of UPT accounted for by far the largest portion of the whole life cycle emissions (measured by carbon dioxide, CO_2). For example, Li et al. (2016) suggested materials production, materials transportation, onsite construction, operation, and maintenance accounted for 4.1%, < 0.1%, 0.4%, 92.1%, and 3.4% of the total emissions respectively.

Specifically, the subway transport system includes the subway traction system (both traction motor and auxiliary equipment such as vehicle equipment, lighting power, and broadcasting system of passenger compartment) and power and lighting system of subway stations (excluding the use of commercial electricity and other operational nature of energy consumption in Shenzhen). The bus transport system includes traditional big diesel bus (TB-D bus), traditional small and medium diesel bus (TM&S-D bus), big electric bus (B-E bus), medium and small electric bus (M&S-E bus), single-decker hybrid bus (SD- H bus), and double-decker hybrid bus (DD-H bus) (see details in Table S2). The scope and system boundary of the streamlined LCA model is detailed in Fig. S1.

2.2. Method

In this study, a streamlined LCA is developed to estimate the carbon emissions from the UPT system in Shenzhen. In detail, the streamlined LCA is an extension of an ongoing initiative around the Product Attribute to Impact Algorithm (PAIA) method developed by Olivetti et al. (2013a,b). This streamlined LCA method maps the intrinsic attributes of products to energy consumption and GHG emissions. The merits of the streamlined LCA model include: data management, process analysis, and results interpretation. Similarly, the uncertainty is well captured via sensitivity analysis. In this study, an evaluation of the data quality and uncertainty was conducted. Due to the complexity of the public transport system, the unit carbon emissions of different types of buses were calculated separately based on the actual performance data which were collected from the Shenzhen Municipal Transport Commission. The carbon emissions of the subway were mainly based on the recorded data of the electricity consumption. Consequently, the unit carbon emissions are calculated.

The annual carbon emissions (CE) of each type of transport activity is calculated according to Eqs. (1) and (2), and thus the total carbon emissions of the UPT system in Shenzhen in a given year is expressed in Eq. (3):

$$CE_{BT,y} = D_{\mathrm{d}} \times U_d \times E_{BT,d} + D_{\mathrm{h}} \times U_h \times E_{BT,h} + D_e \times U_e \times E_{BT,e} \quad (1)$$

$$CE_{ST,y} = U_{t,y} \times E_{ST,w} + U_{s,y} \times E_{ST,w} \quad (2)$$

$$CE_{UPT,y} = CF_{BT,y} + CF_{ST,y} \quad (3)$$

Where, CE is measured by kilogram of CO_2 e; UPT includes both subway (ST) and bus(BT); y is the year; D is the annual travel distance (km per year) of all public buses (consisting of diesel bus, d; hybrid bus, h; and electric bus, e). U is the energy use of bus travel, measured by $L/100$ km or $kwh/100$ km. Emission factors (CO_2 e. per liter, E_{BT}) of various energy types are distinguished as diesel ($E_{BT,d}$), hybrid bus ($E_{BT,h}$), and electric bus ($E_{BT,e}$). $U_{t,\ y}$ is traction electricity use by subway in each year. $U_{s,\ y}$ is the power and lighting electricity use by subway stations in each year. $E_{ST,w}$ is the electricity emission factor (measured as CO_2 e/kWh) of Shenzhen (from South China Power grid).