Resources, Conservation & Recycling 140 (2019) 209–215

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

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

Full length article

Structural contribution and scenario simulation of highway passenger transit carbon emissions in the Beijing-Tianjin-Hebei metropolitan region, China

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ARTICLE INFO

Keywords:
Highway passenger transit
Carbon emissions
Spatio-temporal change
LEAP model
Scenario simulation
BTH region

ABSTRACT

The rapid growth of energy consumption and resulting CO_2 emissions from transportation in China present challenges for decision makers in resolving a balance between demands for energy and environmental sustainability. In China, the major source of carbon (C) emissions derives from the transit system, and this problem is of particular interest in metropolitan regions, however there is a lack of clarity on past and projected future trends of C emissions from transit. This study aimed to model recent (2005–2014) historical spatio-temporal highway passenger transit C emissions (HPTCEs) in the Beijing-Tianjin-Hebei urban region, and to predict future emissions to 2030 under three simulated contrasting management scenarios. We used a long-range energy alternative planning system (LEAP) model to predict emissions under baseline, business as usual growth, and partial and total emission control scenarios. Modeling showed that the total emission control scenario resulted in greater reductions in C emission compared with the baseline growth and partial control scenarios, however, regional total C emissions were predicted to continue to rise by 2030 under all three scenarios. C emissions per passenger kilometer were predicted to decrease over time, while total regional C emissions continued to rise and increase pressure for decision makers to reduce regional C emissions. While HPTCEs were historically greater in Beijing and Tianjin, those from Hebei Province had recently sharply increased to levels greater than in Beijing and Tianjin, and this trend was predicted to continue. This study demonstrates that science-based policy intervention and regulations could reduce C emissions in metropolitan areas.

1. Introduction

About 25% of global carbon dioxide (CO_2) emissions derive from transportation (He et al., 2005; Allen et al., 2009; Shabbir and Ahmad, 2010; Cohan and Sengupta, 2016), and China's entry into the era of motorized highway passenger transit is likely to impact regional energy supply security and carbon emissions (Wang et al., 2016; Lin and Tan, 2017; Wang et al., 2017; Dong et al., 2018). Carbon emissions from mainland Chinese highway transport account for more than 90% of total C emissions from transport and represent the largest regional source of C emissions (Li et al., 2016; Liu et al., 2017a,b; Mulley et al., 2017). The projected increase in number of private cars in China is likely to result in continuing rises in regional C emissions (Fenton, 2017) and presents a significant challenge for C emissions reduction in the country (Meng et al., 2012). The impending nationwide unified carbon market will involve accounting of total regional C emissions that will focus attention on predictions of emissions (Niksa et al., 2017), because they will directly influence quantity and trade in regional C emission quotas. The highway passenger transport carbon emissions (HPTCEs) problem is more intense in metropolitan areas as a result of the associated traffic infrastructure, population and industrial density, and developed social economy (Magazines and Review, 2008; Clark, 2013), and within China, pressures on resources and the ecological environment are greater in the Beijing-Tianjin-Hebei (BTH) urban region than in other metropolitan areas (Tscharaktschiew and Hirte, 2010; Clark, 2013; Wen and Liu, 2016). While previous studies tended

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https://doi.org/10.1016/j.resconrec.2018.09.028
Received 24 April 2018; Received in revised form 23 September 2018; Accepted 25 September 2018

to focus on industrial and residential carbon emissions of BTH Metropolitan Region (Pan et al., 2013; Wen and Liu, 2016; Wang et al., 2017), there is a lack of clarity on the contribution of highway passenger transit to C emissions that limits ability to plan and manage for reductions in future C emissions in metropolitan regions.

Measurement and simulation of transportation C emissions have been explored, and current methods for estimating emissions include collecting data from questionnaires and surveys of individuals that are used to simulate general emissions (Wang et al., 2018a,b,c). For instance, Cao and Yang (2017) estimated passenger transit C emissions from different social circles in Guangzhou City using questionnaires, that were then used to explore the transport characteristics of urban residents and factors that affect transit C emissions, and Xu et al. (2014) obtained basic travel data from urban residents of cities in the Yangtze River Delta (Nanjing, Ningbo, and Changzhou) using questionnaires, from which estimates of C emissions and the impact mechanisms analyzed and derived. Using microscopic traffic and transit surveys of passengers in Zhengzhou, the main city of the Central Plains Economic Zone, Gong et al. (2017) used statistics to analyze spatio-temporal variations and influencing factors of passenger transit C emissions. While the estimation of transit C emissions through surveys and questionnaires is beneficial in the analysis of mechanisms associated with passenger transit behaviors that drive C emissions, it is less accurate than direct measurement of C emissions from vehicle fuel consumption data (Zhang et al., 2016).

Various models have been used to predict transit C emissions (Ekonomou, 2010; Alves et al., 2016; Soto and Jentsch, 2016; Wen and Liu, 2016). For example, Wen and Liu (2016) used the stochastic impacts by regression on population, affluence, and technology (STIRPAT) model, which describes economic, social, and technical factors that influence C emissions, to predict future peak C emissions in five northwestern provinces and districts in China, while Li et al.(2016) used the system dynamics method, which integrates results from cybernetics, information and decision theories, and computer simulations to analyze the structure and behavior of the information feedback system to predict energy consumption and C emissions from urban transit during the 12th Five-Year Plan period in China. The LEAP (Long-range Energy Alternatives Planning) model has been used to monitor urban transport air pollution and energy demand in cities in Pakistan (Shabbir and Ahmad, 2010); this method was designed for energy planning and energy policy analysis, and has been widely applied in C emissions prediction and reduction (Shin et al.,2005; Sadri et al.,2014; Perwez et al., 2015), however it is also appropriate for scenario predictions of highway passenger transit C emissions in metropolitan regions.

Prediction and planning to control and guide highway passenger transit development requires a scientific approach based on measurement and analysis of multi-scenario simulations. Here, we address this knowledge gap, by using modeling to estimate the past and present total amount of HPTCEs in the BTH region and predict their future trend.

2. Materials and methods

2.1. Calculation of highway passenger transit carbon emissions

HPTCEs were calculated at the level of the BTH region and at the level of prefecture cities and above, where fuel consumption was used to estimate HPTCEs at the regional level (Bryant et al., 2015) as follows:

$$C = \sum_{i=1}^{4} Ci \tag{1}$$

$$Ci = \sum_{j=1}^{n} Eij \times rj \tag{2}$$

Table 1
Regional average annual mileage and energy consumption of different types of highway passenger vehicle.
Data source: Annual average mileage was derived from China Urban Statistical Yearbook (http://www.stats.gov.cn/tjsj/); average fuel consumption was taken from the report by the Heidelberg Institute for Energy and Environmental Research (IEE, 2008).

Vehicle	Average annual vehicle distance (km)	Average fuel consumption	Fuel	C emission coefficient
Taxi	71175	15.07 km kg^{-1} 0.07 m^3 km^{-1}	Gasoline Natural gas	2.93 tCO$_2$/t 2.16 tCO$_2$/t
Bus	34000	3.91 km kg^{-1} 0.15 m^3 km^{-1}	Gasoline Natural gas	2.93 tCO$_2$/t 2.16 tCO$_2$/t
Private automobile	18,000	15.07 km kg^{-1}	Gasoline	2.93 tCO$_2$/t
Motorcycle	10,000	50.23 km kg^{-1}	Gasoline	2.93 tCO$_2$/t

$$Eij = Si \times Mi \times Nij \tag{3}$$

where C is the total amount of HPTCEs in BTH region; C_i is the C emission from the i_{th} type of motor vehicle; E_{ij} is the fuel consumption of the i_{th} type of motor vehicle; r_j is the C emission coefficient of the j_{th} type of energy source; S_i is the number of i_{th} type of motor vehicles; M_i is the km of the i_{th} type of motor vehicle; and, N_{ij} is the unit energy consumption of the i_{th} type of motor vehicle. The C emission coefficient (r_j) was calculated based on the C emission quantities per energy unit generated from various fuel utilizing processes. It is a key indicator in this approach that may influence emission estimation. We chose the coefficient adopted in many studies (Ekonomou, 2010; Zhang et al., 2015; Liu et al., 2017a,b; Tian et al., 2017), and we used the C emission coefficient from the 2006 Intergovernmental Panel on Climate Change guidelines for National Greenhouse Gas Inventories (IPCC, 2006; Mi et al., 2017); average fuel consumption was obtained by multiplying different types of passenger vehicle data with average annual distance (Table 1).

The HPTCEs in prefecture-level and above prefecture-level cities were obtained by multiplying the unit passenger C emission with passenger turnover in each city, and then summing the results from the different cities. The turnover of passengers and the number of passenger transit vehicles were derived from the statistical yearbooks for different cities in the BTH region (China, 2013). We calculated emissions from road passenger vehicles that use either gasoline or natural gas, because new energy vehicles and rail transportation use clean energy and electricity that do not directly contribute to carbon emissions in the immediate area. We selected C emission coefficients from 2005 to 2014, and available data from the BTH region to calculate HPTCE as the basis for simulations. C emissions were calculated from 2005, when the three provincial governments of the region reached a consensus of cooperation and development, and the Metropolitan Regional Planning was initiated. Since then, growth of the BTH region as an urban agglomeration has promoted the development of the regional transportation infrastructure and inter-city transport links.

2.2. HPTCEs simulation model

The LEAP model is a scenario-based model widely used for simulation and evaluation of energy and environmental policies of a range of industries at various scales, and its simulation platform has been designed specifically for long-term energy planning of energy supply, energy processing conversion, and terminal energy demand (Huang et al., 2011; Pan et al., 2013). The LEAP model analyses energy consumption processes and makes predictions based on detailed information about technological changes (Shabbir and Ahmad, 2010), and it identifies direction and effects of policy development (Zhao et al., 2011; Pan et al., 2013; McPherson and Karney, 2014).