Ecological Indicators 82 (2017) 392–398

Contents lists available at ScienceDirect

Ecological Indicators

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

Urban road traffic scale analysis from the perspective of atmospheric environmental indicators in Tianjin, China

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ARTICLE INFO

Keywords:
Atmospheric environmental indicators
Transport policy
Environmental carrying capacity
Clean vehicles strategy
Mobility management strategy

ABSTRACT

In order to investigate the largest motor vehicle ownership load within the scope of a city with atmospheric environmental indicators as constraint, this article estimates traffic atmospheric environmental capacity (TAEC) and carrying capacity (TAECC) in Tianjin using the A-value method recommended by the Chinese national standard. Our results indicate that NO_X carrying capacity is a key restraining factor of TAEC. According to the current vehicle emission levels per year and air quality standard, Tianjin can accommodate 4.21 million vehicles. Classified by the vehicle type, heavy trucks and large-sized passenger cars are identified as the most important restrictive factors of TAECC. Then we analyze change of TAECC and TAECC's service life under the circumstances of clean vehicle strategy and mobility management strategy. Clean vehicles strategy represented by the elimination of heavy-polluting vehicles can reduce emissions of vehicles so that it can rapidly enhance the TAECC in the short term. Mobility management strategy represented by the car purchase restriction, which reduces total motor vehicle travel, is indispensable for improvement of TAECC in the long term. On the whole, the clean vehicles strategy and mobility management strategy should be implemented gradually.

1. Introduction

Climate change has caused widespread concern all over the world, at the same time the Chinese government also began to discuss how to deal with climate change (Tian et al., 2016; Shao et al., 2014). More than half of the population lives in cities, but they produce as much as 80% of humanity's greenhouse gas (GHG) emissions (Feng et al., 2013). Therefore, reducing pollutants at city level plays a vital role in response to global climate change (Chen and Chen, 2012; Li et al., 2010). At the district level, the emissions produced by the urban road traffic cause a lot of air pollutions, which directly threaten residents' health. The pollutants are mainly composed of NO_X, HC and CO in EU, and the contribution rates of urban road traffic to these three kinds of pollutants are 58%, 50% and 75%, respectively (Goossens and Meneghini, 2006). In addition, the urban road traffic also causes vast pollution in PM and SO_2 (Borrego et al., 2016). Nowadays in China, accompanied with a rapid rise in vehicles and traffic volumes, the amount of the pollutant emissions produced by urban road traffic is increasing, and it has become a major air pollution in cities. There were 279 million vehicles in China in 2015, Nitrogen Oxide discharged from vehicles is 5.849 million tons, which is about 30% of Chinese total emissions. It also is the important cause of the haze, photochemical smog pollution. Especially in very large cities such as Beijing and Shanghai and densely populated areas in the east, contribution rates of PM from vehicle emissions is about 30%, even more than 50% in extreme adverse weather conditions (MEPPRC, 2016).

In the evaluation of urban transport system efficiency among 34 Chinese cities, the sustainable development efficiency of Tianjin's urban transport system only ranked 31. It is so poor and just a little better than Guangzhou, Beijing and Shanghai which belong to first-tier cities, namely the largest megacities in China (Wei et al., 2013). By investigating GHG emissions produced by Beijing, Tianjin, Shanghai and Chongqing, which are municipality cities, the GHG emissions of transport sector increased from 4% in 1995 to 32% in 2009 in Beijing, increased from 1% in 1995 to 9% in 2009 in Tianjin, increased from 6% in 1995 to 18% in 2009 in Shanghai, and increased from 3% in 1997 to 7% in 2009 in Chongqing (Liu et al., 2012). The proportion of GHG emissions from transport sector in Tianjin has increased by nine times, which is the fastest among the four municipalities. More importantly, road traffic emissions have become the main source of air pollution in Tianjin, which is the important cause of haze and photochemical smog pollutions as well (Liu and He, 2012; Uherek et al., 2010), and its

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http://dx.doi.org/10.1016/j.ecolind.2017.07.013
Received 26 January 2017; Received in revised form 22 June 2017; Accepted 6 July 2017
1470-160X/

contribution rate for PM 2.5 is between 20% to 30% (He et al., 2013). In order to reduce air pollution and transform urban traffic's unsustainable development mode, this article presents research carried out on traffic atmospheric environmental capacity (TAEC) and traffic atmospheric environmental carrying capacity (TAECC) in Tianjin.

Buchanan (1963) put forward the traffic environmental capacity (TEC) in "*Traffic in Towns*", namely the maximum number of moving and stationary vehicles per unit time that a road or an area can afford, which does not cause environmental degradation. With the proposal of TEC, extensive research had been carried out in the US, Britain, Australia and other countries. Sharpe and Maxman (1973) gave the method to calculate TEC, based on the perceived air pollution. Thereafter, Holdsworth and Singleton (1979, 1980) defined TEC as the maximum number of motor vehicles, which will not bring environmental degradation in a certain time under the same external conditions. Shiran (1997) explained the reason why the atmospheric pollution is not taken into account in TEC. Although atmospheric pollution is the main contributor to the environmental pollution, it is difficult to be measured quantitatively. What's more, the uncertainty about the diffusion of atmospheric pollution is so great, that it is not suitable to take atmospheric pollution as a static indicator when we evaluate the environmental impact of transport at the microcosmic level. The TEC research based on atmospheric pollution is meaningful only at the macroscopic level. Then Li et al. (2009a) pointed out that due to the introduction of atmospheric pollution, the research about TEC has been expanded from micro level to macro level.

Research studies on TEC have been carried out in China in recent years. Wei et al. (1997) defined TEC as the maximum load of pollutant discharge or maximum usage of environment resources from a transport system, maintaining the human existence, ecological environment and resource usage in harmony at the same time. Due to the restraint of TEC, the total traffic volume is limited in a specific area. The development of a transport system relies on the environmental resources and releases a certain amount of pollutants into the environment. This load capacity that traffic applies on the environment is called traffic environmental carrying capacity (TECC). Since then Chinese scholars have carried out a large amount of theoretical and empirical research on TEC and TECC. Cheng (2004) proposed the influential factors of TECC, which mainly include environment, resources, economic and social psychology. Liu et al. (2002) analyzed the input and output model of pollution in the environment system, then set up a dynamic model for TECC. Zhao (2005) calculated traffic atmospheric environmental capacity (TAEC), which only consider the gas pollutants and ignore the noise and vibration, and traffic atmospheric environmental carrying capacity (TAECC) by Single box model[1] in Chengdu of China. Yang and Wang (2006) predicted traffic volume of highway network based on TECC. Li et al. (2009b) established a linear optimization model about TEC based on the atmospheric pollution expansion and dissemination theory of environmental science. Wang (2009) studied motor vehicle amount development in the new area of Wuhan city with TAEC as a constraint. Zhao (2012) evaluated car ownership in Shenyang based on TECC. Wang (2012b) calculated TEC and TECC in Jilin province, and then investigated the urban traffic system's impact on the environment by the DEA method. Wang (2012a) evaluated TAEC and TAECC with NO_X as a constraint indicator. In summary, the research about TEC and TECC focus on the maximum load pollutants and motor vehicle ownership within a city in the macro perspective.

Based on the above literature review and the need for research, this article defined TAEC as the maximum atmospheric pollutants load produced by a traffic system, which should meet the relevant environmental air quality standard in a specific period of time and place. TAEC was restricted by social surroundings characteristics (such as urban functional division, industrial structure and urban traffic demand, etc.), natural environment characteristics (such as climate, hydrology, vegetation conditions, natural environment background value, etc.), environment quality goals and other factors. TAECC is defined as the maximum motor vehicle ownership load under constant external conditions (all various pollutant annual emissions of all kinds of motor vehicles and other factors are constant) in given TAEC constraints. If TAEC is invariable, TAECC mainly depends on emissions per motor vehicle per kilometer and energy consumption intensity and is closely related to the micro technology level. In addition, due to the differences in emission intensity, energy consumption and traffic supply from different modes of transport, TAECC is different in various structures of the transport systems at the same TAEC, as well. In general, TAECC is in dynamically updated changes. In the short term, it is essentially unchanged decided by real existing economic and technological level. However, it is a variable which is rising with the advancement of economic and technological level in the long term.

Section 2 of this article mainly introduces the calculation method of TAEC and TAECC, and related data in Tianjin, the largest port city in northern China; Section 3 gives the result of TAECC and indicates restriction factors of TAECC, then forecasts motor vehicle ownership per 1000 persons by the Logistic function and how long TAECC can be depleted; Section 4 analyzes impact of motor vehicles in different phases of emission standards on the TAECC and change of TAECC and TAECC's service life under the circumstances of clean vehicle strategy and mobility management strategy, then gives the relevant policy implication; finally, the conclusions are made in Section 5.

2. Methodology

TAEC of Tianjin is calculated by the A-value method which is from the GBPT13201-91*"The technical method of local atmosphere pollutants emission standards"*.[2] The concentrations background of various pollutants in Tianjin were ignored in the process of concrete calculation:

$$Q_a = AC_{si}\frac{S_i}{\sqrt{S}} \tag{1}$$

where Q_a is the ideal atmospheric environmental capacity in Tianjin, 10^4t/a; A is the regional environmental capacity coefficient, (10^4 km^2/a); C_{si} is the average daily concentration limit of the i kind of pollutants in this local area, mg/m^3; S_i is the area of i-th function area, km^2; S is the total area of A-value controlled area, km^2.

The atmospheric pollutants discharged by motor vehicles have reached 46,079 million tons in China in 2011. Among them, NO_X is 6.375 million tons, HC is 4.413 million tons, CO is 34.671 million tons, and PM is 621,000 tons (MEPPRC, 2012). As the main pollutants from motor vehicles are NO_X, CO, PM and HC in China, these were chosen as the constraint indicators to evaluate the TAEC of Tianjin.

According to the A-value table of capacity control coefficient in different regions (shown in Table S1 in Appendix in Supplementary material) which is given from the GB PT13201-91 and the recommended A-values (Li et al., 2005), A-value in Tianjin was 4.34 10^4 km^2/a. Since Tianjin belongs to the second class[3] in GB3095-2012 "ambient air quality standard", so the function area is equal to the total area of Tianjin which is 11,917 km^2. Besides, there is no specific

[1] A simple Monte Carlo single-box model is presented as a first approach toward examining the relationship between emissions of pollutants from fuel/cookstove combinations and the resulting air pollution (IAP) concentrations (Johnson et al., 2011).

[2] This GB is applied to the guidance of atmosphere pollutants emission standards in all provinces, autonomous regions and municipalities in China. The control goal of GB is to achieve atmosphere quality standard. It enacts local atmosphere pollutants emission standards by the method of the limit total emission in control area on the basis of the atmospheric pollutants diffusion dilution law.

[3] The air environmental function area is divided into two categories: one category includes nature reserves, scenic areas and other areas that need special protection; the other includes residential areas, commercial traffic residents mixed areas, cultural areas, industrial parks and rural areas.