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Research Paper

Effects of land use and transportation on carbon sources and carbon sinks: A case study in Shenzhen, China

Wenting Zhang[a], Bo Huang[a,*], Dong Luo[b]

[a] Department of Geography and Resource Management, The Chinese University of Hong Kong, Hong Kong
[b] Changjiang Project Supervision and Consulting Co., Ltd., Wuhan, PR China

HIGHLIGHTS

- We used a coefficient approach to determine the number of carbon sinks and carbon sources in Shenzhen.
- We used a traffic-prediction tool to determine the traffic flow based on the distribution of land use and road networks.
- We used the aforementioned models to estimate the number of carbon sinks and carbon sources in Shenzhen.
- We presented the spatial variations of net carbon source in Shenzhen.
- We explored the relationship between land-use changes and the variations of net carbon source.

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ABSTRACT

Carbon-sink and carbon-source estimation are of significance for carbon-emissions reduction. In this paper, we evaluated Shenzhen's annual carbon budget from 2000 to 2008 by measuring the presence of carbon sinks and carbon sources in the city. First, we used a coefficient approach based on factors such as land-use status and crop yield, to determine the number of carbon sinks in Shenzhen. Second, we identified urban carbon sources such as human respiration, industrial fossil-fuel consumption, cropland soil, livestock and transportation. We used a traffic-prediction tool, namely the four-step model, to determine traffic flow and the average speed of vehicles based on land-use types and the spatial distribution of road networks. Finally, we used the aforementioned methods to estimate the number of carbon sinks and carbon sources in Shenzhen from 2000 to 2008, along with its net carbon source. The results show that the number of carbon sinks decreased and the number of carbon sources increased in Shenzhen between 2000 and 2008. However, the net carbon source per million GDP decreased, which suggests that carbon-reduction efficiency improved during this period. Urban expansion and forest reduction were the major causes of the observed carbon-sink reduction. We identified transportation and industrial fossil-fuel consumption as Shenzhen's main carbon sources. The former produces high concentrations of CO_2; the latter is related to the growth of secondary industries. In addition, the spatial distribution of the net carbon source from 2000 to 2008 indicated that Shenzhen's net carbon source increased both spatially and temporally during this period.

1. Introduction

More than 50% of the world's population live in urban areas (based on 2010 data), and this figure is predicted to increase to 70% by 2050 (Burgess et al., 2008). Populous cities are characterized by high concentrations of vehicles, industries and high energy consumption. In fact, 76% of the global consumption of coal occurs in cities, even though they cover less than 1% of the earth's surface (Sullivan, 2010). Therefore, the reduction of carbon-dioxide (CO_2) emissions from urban systems is crucial to global CO_2-emissions reduction and low-carbon development. The C40 Large Cities Climate Leadership Group reported that 80% of the world's anthropogenic greenhouse gases (GHGs), which are mainly composed of CO_2, are emitted from cities and that the world's total urban emissions are increasing at a rate of 1.8% per year. Furthermore, GHGs emitted from cities in developing countries are expected to increase at a higher than average rate. It is clear that cities are now the main contributors to the greenhouse effect and global warming. At the same time, they are adversely affected by global climate warming. For example, urban heat islands (UHIs) increase the incidence of human mortality during high-heat events (Lo & Quattrochi, 2003). In addition, excessive CO_2 emissions

* Corresponding author. Tel.: +852 3943 6536.
E-mail address: bohuang@cuhk.edu.hk (B. Huang).

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disrupt the urban ecological balance. Consequently, human health and living and working conditions in urban areas are degraded by excessive CO_2 emissions.

As CO_2 has been scientifically proven to be the major cause of the greenhouse effect (Goodale et al., 2002; Houghton & Hackler, 2003; Liu, Zhou, Wei, & Shu, 2012; Sarmiento et al., 2010; Yang, Hao, Lv, Chen, & Wang, 2012), scholars have paid increasing attention to CO_2 emissions (Hildemann, Klinedinst, Klouda, Currle, & Cass, 1994; Koerner & Klopatek, 2002; Mulholland & Seinfeld, 1995). As excessive levels of CO_2 can be moderated by the natural CO_2-absorbing properties of soil and plant-life, researchers should consider conducting CO_2-emissions analysis with reference to carbon sources and carbon sinks. Carbon sources are defined as any of the processes, activities or mechanisms that release CO_2 into the atmosphere, and carbon sinks denote processes or activities that remove CO_2 from the atmosphere.

Land-use changes, especially forest variation, are currently considered to have the greatest influence on regional carbon sinks and carbon sources. Liu et al. (2012) analyzed the effects of deforestation in China using national forest-inventory datasets, and concluded that forests in China played an increasing role as carbon sinks between 1984 and 2003. Goodale et al. (2002) analyzed the forest-sector carbon budgets of Canada, the United States of America, Europe, Russia and China and found that northern forests and woodland constituted a total sink consisting of living biomass, forest products, dead wood, the forest floor and soil organic matter. Dong et al. (2003) used a regression model to represent the relationship between forest biomass and the normalized-difference vegetation index of Canada, Finland, Norway, Russia and the United States of America during one period, and of Sweden during two periods. Despite these efforts, however, the scholarship on carbon sinks and carbon sources in urban settings is still very limited.

Compared with natural systems, urban areas are more deeply affected by human activities such as (1) human respiration, (2) transportation, (3) industrial production, and (4) livestock farming. These activities create complex carbon-sink and carbon-source processes in urban systems, and cannot be deduced from land use and land-use changes. Using a coefficient method (Yang et al., 2012), we can easily identify the urban carbon sources constituted by human respiration, industrial production and livestock farming from statistical data. In contrast, traffic emissions are difficult to calculate using a coefficient method for the following reasons. First, statistical and spatial data regarding transportation are limited in some areas, which make it impossible to identify the number of vehicles and the corresponding travel distance of each vehicle in these areas. Second, the factors that determine traffic CO_2 emissions vary according to different traffic conditions. For example, a vehicle in stop–start motion will emit more CO_2 than a vehicle traveling in a fluid road system. It seems, therefore, that any calculation of the carbon source constituted by a transportation system must take into account traffic conditions and the spatial distribution of roads, as well as the number of vehicles on the road. These factors, however, cannot be accommodated by a simple coefficient method. Many scholars have, thus, used other methods to evaluate the CO_2 emitted from the transportation sector and to investigate traffic CO_2 emissions (Anjaneyulu, Harikrishna, & Chenchuobulu, 2006; Contini, Donateo, Elefante, & Grasso, 2012; Keuken, Jonkers, Zandveld, Voogt, & Van den, 2012). For example, Shu, Lam, and Reams (2010) proposed a volume-preserving interpolation method to obtain a more realistic spatial depiction of CO_2 emissions from the transportation sector at a fine spatial resolution. Lu, Lin, and Lewis (2007) suggested that rapid economic growth and a corresponding increase in vehicle ownership are the most important causes of increased CO_2 emissions. However, although these studies of traffic CO_2 emissions are relevant to carbon analysis in urban systems, across-the-board research on the urban carbon budget, including land-use changes, industrial fossil-fuel consumption and traffic emissions, is still lacking.

Due to the limitations of the existing research into CO_2 emissions in urban areas, we use carbon-sink and carbon-source theory (Goodale et al., 2002; Houghton & Hackler, 2003; Liu et al., 2012; Sarmiento et al., 2010; Yang et al., 2012) to address, in both spatial and temporal dimensions, the absorption and emission of CO_2 which is one of the most important GHGs released into the atmosphere by human activities (Eggleston, Buendia, Miwa, & Ngara, 2006; King, Hayes, Huntzinger, West, & Post, 2012) in urban systems.

Along with its increasing economic development and population growth, China has become one of the world's leading CO_2 emitters (Yang et al., 2012). It contributed 13.5% of global CO_2 emissions in 2000, which made it the world's second largest emitter after the United States of America (Zhang, 2000). Furthermore, China's contribution is expected to exceed that of the United States of America by 2020 if the country continues to develop at its current rate (Zhang, 2000). Therefore, the study of CO_2 emissions in China is significant for the reduction of CO_2-emissions on a global scale. The problem of excessive CO_2 emissions is particularly severe in China's cities, especially those undergoing rapid development such as Beijing, Shanghai, Guangzhou and Shenzhen (Dhakal, 2009; Li, Chen, et al., 2010; Li, Qiu, et al., 2010; Zhang & Cheng, 2009). Since rapidly developing cities in China are suffering the consequences of excessive CO_2 emissions first hand, their experiences are critical to the future of other cities in the country. Shenzhen will be China's first low-carbon ecological demonstration city, and it is intended by the Ministry of Housing and Urban-Rural Development to provide a good example to the whole country. In addition, it has measurable heat islands and elevated carbon levels (Chen, Gong, Wu, & Yu, 2012; Xie, Wang, Fu, & Zhang, 2013). Shenzhen is, thus, an appropriate location for our case study.

The remainder of this paper is organized as follows. In the second section, we provide background details of Shenzhen's economic development including land-use patterns and population growth. In the third section, we present our chosen method of urban carbon-source and carbon-sink calculation; we use a traffic-prediction model, namely, the four-step model (FSM), to predict traffic flow and actual speed according to land-use patterns in Shenzhen and the spatial organization of its road network. In the fourth section, we provide the predicted outcomes of these quantitative and spatial measurements of Shenzhen's carbon sinks and carbon sources. Finally, in the last two sections we discuss the fitness of the proposed method and its potential benefits for other cities exhibiting excessive CO_2 emissions.

2. Study area and data

2.1. Study area

Shenzhen is located at the center of the Pearl River Delta in the south of China (between 22°27′N and 22°52′N latitude, and between 113°46′E and 114°37′E longitude), and has a total terrestrial area of approximately 1952.85 km^2, according to the Shenzhen Statistical Yearbook (Shenzhen Statistics Bureau, 2009). The dominant vegetation types in Shenzhen are evergreen broad-leaved mixed forest, garden plots, cropland and pastureland. In 2008, Shenzhen's land-use coverage consisted of cropland, garden plots, forest, pastureland, built-up areas, transportation, water bodies and unused land (Fig. 1). Over the last three decades, the natural elements of Shenzhen's land coverage have been drastically reduced due to urban expansion. Shenzhen was established in 1980 as the country's first experimental, special economic zone under China's Reform and Open-Door Policy. Since its establishment, Shenzhen