Cities 44 (2015) 112–120

Contents lists available at ScienceDirect

Cities

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

The role of urban green infrastructure in offsetting carbon emissions in 35 major Chinese cities: A nationwide estimate

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ARTICLE INFO

Article history:
Received 24 October 2014
Received in revised form 16 January 2015
Accepted 24 January 2015
Available online 20 February 2015

Keywords:
Urban green infrastructure
Carbon storage
Carbon sequestration
Carbon emission
Climate change mitigation
China

ABSTRACT

The carbon balance in urban areas has become a major research challenge and a principal policy concern in efforts to address anthropogenic climate change. Rapid urbanization and industrialization in China urge the search for integrated strategies to mitigate and adapt to climate change, which not only limit to traditional infrastructure sectors, but also cover urban green infrastructure, because plants and soils function as carbon sinks through biotic sequestration. This study presents a nationwide study about how urban green infrastructure could contribute to the carbon balance in 35 major Chinese cities. By the end of 2010, the total area of urban green spaces (the dominant components of urban green infrastructure) accounts for 6.38% of the total land area of these cities and represented 51.7% of the total urban green spaces of all 657 cities in China. Based on empirical data from the literature, the total amount of carbon stored in the vegetation of the urban green infrastructure of 35 cities was estimated at 18.7 million tons, with an average carbon density of 21.34 t/ha. In 2010, the amount of carbon sequestration totaled 1.90 million tons with an average carbon sequestration rate of 2.16 t/ha/year. Collectively, only 0.33% of the carbon emissions from fossil fuel combustion can be offset, ranging from 0.01% in Hohhot to 22.45% in Haikou. Nevertheless, the dominance of young vegetation stands in Chinese urban green infrastructure suggests this small carbon sequestration efficiency could become substantial in the near future, given that appropriate policies and management practices are adopted to promote urban green infrastructure for climate change mitigation and adaptation.

Introduction

The carbon balance in urban areas has become a major research challenge and a principal policy concern in efforts to address anthropogenic climate change, as cities are both drivers of the increasing concentration of atmospheric carbon dioxide (the predominant greenhouse gas) and also major players in the search for effective strategies to make human society more sustainable and improve the wellbeing of urbanites (Davies, Edmondson, Heinemeyer, Leake, & Gaston, 2011; Escobedo, Varela, Zhao, Wagner, & Zipperer, 2010; Feliciano & Prosperi, 2011; Liu & Li, 2012; Neirotti, De Marco, Cagliano, Mangano, & Scorrano, 2014; Pataki et al., 2006; Romero Lankao, 2007; Rosenzweig, Solecki, Hammer, & Mehrotra, 2010; Strohbach, Arnold, & Haase, 2012). Only through the transformation of urban infrastructure, not only limited to traditional sectors such as transportation and buildings, but also covering all infrastructure, particularly implementing green infrastructure as a carbon sink (Escobedo et al., 2010; Gill, Handley, Ennos, & Pauleit, 2007; McPherson, Xiao, & Aguaron, 2013), will cities be able to mitigate and adapt to climate change (Hunt, 2004). However, the research combining analyses of energy consumption, CO_2 emissions, and plant (and soil) carbon pools has only begun (Pataki et al., 2006) and received increasing attention recently (Churkina, Brown, & Keoleian, 2010; Pataki et al., 2011; Pickett et al., 2011).

Urban green infrastructure (including a wide range of natural elements in urban areas such as greenways, parks, gardens, green roofs, woodlands, waterways, community farms, forests, and wilderness areas) can serve as an effective strategy for microscale, mesoscale, and even macroscale climate change mitigation and adaptation because vegetation can capture and securely store carbon through biotic sequestration (Escobedo et al., 2010; Jo, 2002; Nowak & Crane, 2002; Pataki et al., 2006; Rowntree & Nowak, 1991; Vidrih & Medved, 2013). Trees close to buildings could affect local microclimate directly by shading and blocking wind, as well as influencing energy use and consequently reducing carbon emissions from power plants thus affect climate indirectly (Jo & McPherson, 2001; Nowak & Crane, 2002). At the city/regional level, vegetation cover would influence incoming solar radiation (Heisler,

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http://dx.doi.org/10.1016/j.cities.2015.01.005
0264-2751/

1986), relative humidity, surface roughness and albedo, and heights of boundary-layer, hence affects various aspects of local meteorology (Arnfield, 2003; Nowak & Dwyer, 2007). At the global level, vegetation in urban green infrastructure can act as passive carbon sinks by assimilating carbon through photosynthesis and storing carbon as biomass (Nowak & Crane, 2002; Nowak, Greenfield, Hoehn, & Lapoint, 2013). It is estimated that urban trees in the 50 US states store a total of 643.2 million tons of carbon with a gross sequestration rate of 25.6 million tons per year (Nowak et al., 2013). Other studies have assessed the carbon balance in different cities such as Florence in Italy (Vaccari, Gioli, Toscano, & Perrone, 2013), Leipzig in Germany (Strohbach et al., 2012), and Chuncheon, Kangleung, and Seoul in South Korea (Jo, 2002). Thus far, however, there have only been a few attempts to quantify carbon storage and sequestration in individual Chinese cities (e.g., Liu & Li, 2012; Zhao, Kong, Escobedo, & Gao, 2010; Zhao, Ouyang, Xu, Zhang, & Meng, 2010).

China is of pivotal importance in the context of climate change because it is a principal contributor to global-scale CO_2 emissions (Chen et al., 2007; Global Carbon Project, 2008). Much of this CO_2 emission is attributable to urban areas. China's rapid urbanization and industrialization, accompanied by the extensive expansion of urban infrastructure and the increase of energy consumption, have resulted in a steadily increasing CO_2 emission (Dhakal, 2009; Li et al., 2009). Because projections show that China's urbanization will continue to grow rapidly (UN, 2011), establishing efficient and healthy urban systems has become a national priority (Li et al., 2009). It poses a prodigious challenge that demands recalibrating many of the institutions and instruments with which urban systems can be optimized to mitigate and adapt to climate change in China.

A considerable knowledge gap remains in understanding the opportunity of integrating urban green infrastructure into carbon reduction scenarios, which has been largely unacknowledged in China. Although planting more trees has been emphasized as an integral effort for climate change mitigation (Fu, Li, & Huang, 2009; Liu & Yin, 2012), the vegetation in urban areas has been excluded from the national forest inventory (the State Forestry Administration of China; Liu & Yin, 2012). Therefore, this study investigated (a) the magnitude of the carbon storage and sequestration by urban green infrastructures, and (b) the efficiency of offsetting CO_2 emissions from fossil fuel consumption in 35 major cities in China. Based on empirical data from the literature, the preliminary findings of this study can serve as a foundation to integrate urban green infrastructure into formulating effective strategies for climate change mitigation and adaptation in China.

Methods

Study area and urban green infrastructure

In this study, 35 major Chinese cities were covered, including four municipalities (Beijing, Shanghai, Tianjin, and Chongqing), 26 provincial capitals, and five economically critical cities (Fig. 1, Table 1). These cities are the most important political, economic, and cultural centers in the country, as defined in the National Plan of China. In addition, they represent rapid economic and industrial growth, extensive urbanization and infrastructure development, and the accelerated changes in technology, lifestyles, and society (Dhakal, 2009). These cities consume nearly 40% of the total energy produced in the country and emit CO_2 at a similar level (Dhakal, 2009). Therefore the implementation of new measures and policies for climate change mitigation is crucial in these cities.

Rapid industrialization and urban expansion presents numerous environmental challenges, one of which is the maintenance of urban green space (Tzoulas et al., 2007; Zhou & Wang, 2011). Originally vegetated lands were replaced with built structures,

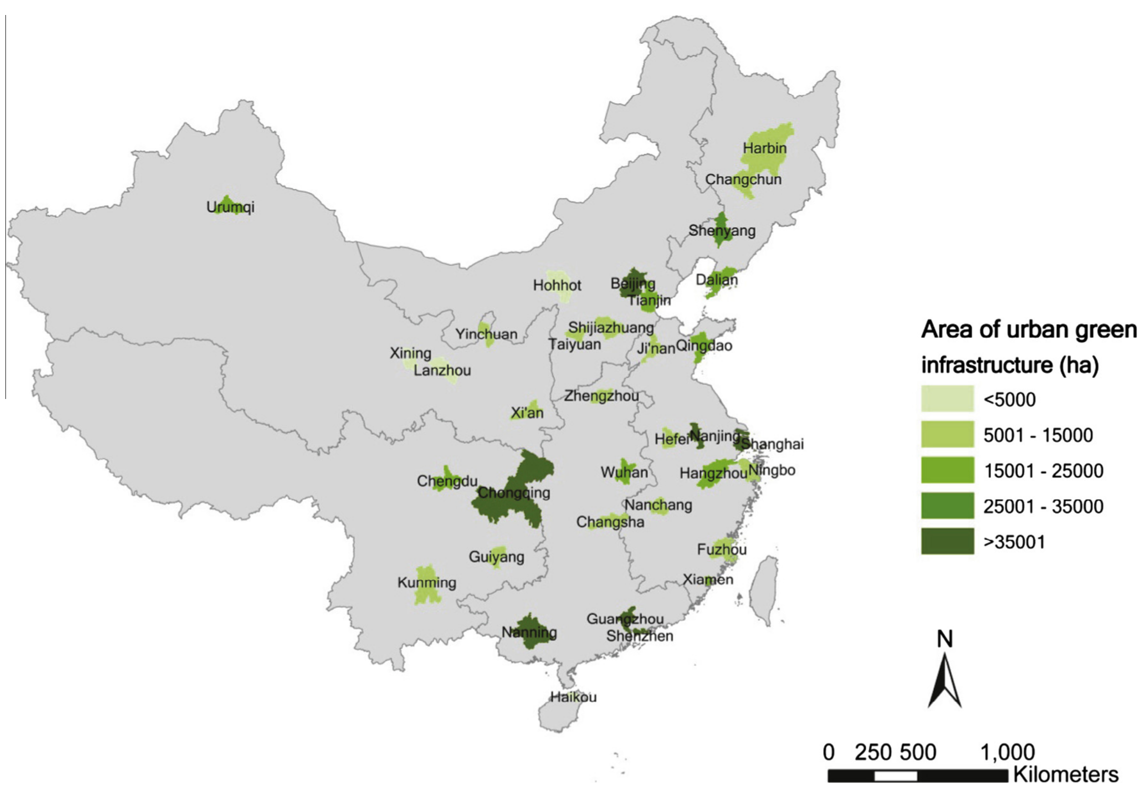

Fig. 1. The area of urban green infrastructure in 35 major Chinese cities. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)