Chapter 134
Urban Green Land Carbon-Sink in Different Functional Cities: The China Case

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134.1 Introduction

Due to the burning of a large amount of fossil fuels, deforestation and land use change as a result of industrialization and urbanization, the carbon emission is increasing, which leads to greenhouse effect and global warming. The climate change and global warming will contribute to a serious of significant economical and ecological consequences. In fact, 76% of the global consumption of coal and 71% of global carbon emissions occur in cities, even though they cover less than 1% of the earth's surface (Sullivan 2011). 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, and scholars around the world have paid increasing attention to CO_2 emissions (Hildemann et al. 1994; Koerner and Klopatek 2002; Mulholland and Seinfeld 2011; Shen et al. 2016, 2017).

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; Shuai et al. 2017). It contributed 13.5% of global CO_2 emissions in 2000, which made it the

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world's second largest emitter after the United States of America (Zhang 2000). 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. For example, 40% of the nationwide consumption of energy and 40% of nationwide carbon emissions occurs in the 35 provincial capitals, which only have less than 40% of the population of China (Dhakal 2009). At the same time, with China undergoing rapid urbanization, Chinese cities have a decisive impact on the CO_2 emissions and low-carbon development in the country, and they are the most promising areas of carbon reduction. The pressure on China due to international negotiations related to reducing emissions is greater than ever. To mitigate this pressure, China officially submitted Intended Nationally Determined Contributions (INDCs) before the United Nations Conference on Climate Change held in Paris in 2016, which clearly states that carbon dioxide emissions per unit of GDP in China will peak around 2030 and China will try best to evidence this peak target as soon as possible. China also made some specific targets that carbon dioxide emissions per unit of GDP would decline by 60–65% in the 2030 in the comparing with that in 2005, the proportion of non-fossil energy in the primary energy consumption would increase by around 20%, and forest stock would increase by 4.5 billion cubic metres. To achieve the reduction targets mentioned above, the national emission reduction targets are allocated to various provinces and municipalities by the central Chinese government.

There are various ways which can be used to reduce carbon dioxide intensities, such as an integrated CO_2 capture and storage (CCS) operation system. However this technology is not attractive in China in the current stage because it is an expensive technology for limiting CO_2 emissions (Liang and Wu 2009). On the contrary, the method of increasing UGLC is widely considered a better way among these methods, since it can not only remove carbon dioxide from the air but also improve ecological environment.

China has an vast area with 272 prefecture-level cities and more than 600 county-level cities in 2014. These cities are different in several aspects such as population size, GDP, resources endowment, urbanization, development stage and energy consumption structure. These aspects are also carbon emissions, driving factors, so there are differences in the structure of UGLC of different cities. The aim of this paper is to provide important references to the Chinese government for allocating the national emission reduction targets to various provinces and municipalities by analyzing Urban Green Land Carbon Sinks in different functional cities of China.

Carbon reduction can be made possible by both reducing carbon sources and increasing carbon sinks at the same time. A considerable amount of research on carbon source and carbon sink in the context of China has been done. However, these studies were carried out at the provincial scale not at the urban scale and they do not provide much attention to the relation of carbon-sink and the function of cities in China. For example, Lu et al. (2013) made an overall estimation of carbon emissions from energy consumption, and carbon sinks from forest, grassland and arable land at the provincial scale. Current researches related to urban carbon sinks are mostly for a single city or a group of cities which adjoin each other. Taking the highly urbanized city of Shenzhen as an example, Ye et al. (2012) adopted the IPCC (Intergovernmental Panel on Climate Change) default factor method and carbon sink model to analyze the basic characteristics of the urban carbon sinks. Yang (2010) made an analysis to show the present situation of carbon source and carbon sink, and the distribution of carbon emission in different industries in Shanghai. The study of Yang (2012) demonstrated the emissions from energy activities, industry processes, waste disposal, cropping and breeding industry and carbon sink of wetland and forest to monitor the performance of greenhouse gas in Chongqing. Yi et al. (2015) evaluated the inventory of carbon sources and sinks in Yangtze River Delta Region during 1995–2010 and analyzed their spatiotemporal patterns. Yang and Zou (2013) investigated the status of low carbon economy in the East of China between the year of 2005—2011 in the view of carbon source, carbon sink and carbon productivity. Obviously, the results of those research mentioned above are often only available in a certain regions or in a particular city, and can not be promoted widely. Therefore, this paper aims to fill the gap by analyzing the urban green land carbon-sinks in different functional cities in China and explore the relation of the both.

The remainder of this paper is organized as follows. In the second section, we present our method of classifying the 269 prefecture-level cities of China based on their function, the classification results and chosen method of UGLC calculation. In the third section, we predicted outcomes of these quantitative measurements of 289 cities' UGLC. Finally, we analyze the urban green land carbon-sink in different functional cities of China.

134.2 Data and Method

134.2.1 Data

Our data about those indexes listed in Table 134.1, which was used for classifying the 269 prefecture-level cities in China, are obtained from the *China City Statistical Yearbook 2006–2015*. The data on area of green land used for UGLC calculation are from *China Urban Construction Statistical Yearbook 2006–2015*.

Table 134.1 Indexes for evaluating the function of cities

NO.	Indexes
1	Economic factor
1.1	Per Capita GRP
1.2	Number of Industrial Enterprises
1.3	Investment in Fixed Assets (Excluding Rural Households)
1.4	Total Retail Sales of Consumer Goods
1.5	Total Sales of Commodities of Enterprises above Designated Size in Wholesale and Retail Trades
1.6	Primary Industry as a Percentage of GDP
1.7	Secondary Industry as a Percentage of GDP
1.8	Tertiary Industry as a Percentage of GDP
2	Social factor
2.1	Total population at Year-end
2.2	Number of Beds of Hospitals and Health Centers
2.3	Collections of Public Libraries per 100 persons
3	Labor Force and Employment
3.1	Persons Employed in Primary Industry
3.2	Persons Employed in Mining Industry
3.3	Persons Employed in Manufacturing Industry
3.4	Persons Employed in Construction Industry
3.5	Persons Employed in Real Estate
3.6	Persons Employed in Traffic, Transport, Storage and Post
3.7	Persons Employed in Catering and Business Services
4	Traffic factor
4.1	Total volume of transport
4.2	Total volume of freight
4.3	Per Capita Area of Paved Roads in City
5	Resources and environment
5.1	Per Capita Area of Green Land
5.2	Area of Built-up Area Covered by Green
5.3	Volume of Industrial Waste Water Discharged

134.2.2 The Functional Classification of 268 Prefecture-Level Cities in China

Urban Function refers to the tasks and the roles which cities should undertake in the political, economic and cultural fields of the country or region. Cities differ in function, which has long been recognized (Harris 1943) and functional types such as industrial, commercial, mining, university, and resort towns have been differentiated by numerous researchers (Tian and Yang 2010; Belsky and Karaska 1990). However, due to the complexity of factors influencing city function and the situation where most cities have a variety of functions, literature on the functions of cities is deficient in studies on criteria for distinguishing types and in classifications. This paper attempts to remedy these deficiencies by a quantitative method of functional analysis. First, this paper establishes a set of indexes for evaluating the function of cities, which was showed in Table 134.1. Second, by the technical support of software SPSS 20.0, the method of principal components analysis and clustering analysis are adopted to analyze these indexes and classify these 268 prefecture-level cities.

134.2.3 Estimation of UGLC

According to the United Nations Framework Convention on Climate Change (UNFCCC) which entered into force on February 16, 2005, carbon sinks are processes, activities or mechanisms that remove CO_2 from the atmosphere (Yang et al. 2012).

Urban green land carbon-sink (UGLC) is measured by estimating area of urban green land and the carbon-sink factor of green land (Eq. 134.1).

$$\text{Carbon-sink}_{\text{green land}} = C_{\text{green land}} \times S_{\text{green land}} \quad (134.1)$$

Carbon-sinkgreen land is the urban green land carbon-sink (tons), Cgreen land is the carbon-sink factor of urban green land (tons C/km^2), and Sgreen land is the area of the urban green (km^2). According to existing studies on carbon sinks (Fang et al. 2007; Jiang 2010), together with regional green land characteristics, the carbon-sink factor of urban green land is commonly adopted as 3380 tons C/km^2.

134.3 Result

134.3.1 The Results of the Functional Classifications Between 289 Prefecture-Level Cities

By using the software SPSS 20.0, six main factors are formulated, as shown in Table 134.2, as the results from applying the method of principal components analysis. The applications of the six factors are further explained as follows: (1) The first factor was labeled " integrated cities", as the load values of the items on this factor did not have much different from each other. (2) The second factor was labeled "industrial cities", as the load values of the industrial-related items (1.2, 1.7, 3.3, 3.4) on this factor is larger. (3) The third factor was labeled "transportation cities", as the load values of the transportation-related items (3.6, 4.1) on this factor is larger. (4) The fourth factor was labeled "cultural and tourist cities", as the load values of the cultural and tourist related items (2.3, 5.1) on this factor is larger.

Table 134.2 Exploratory factor analysis

Items	Factor 1: integrated cities	Factor 2: industrial cities	Factor 3: transportation cities	Factor 4: Cultural and tourist cities	Factor 5: larger-scale cities	Factor 6: resource-dependent cities
1.1 Per Capita GRP	−0.046	0.012	0.137	0.040	0.096	0.015
1.2 Number of Industrial Enterprises	−0.038	0.302	0.048	−0.076	–	–
1.3 Investment in Fixed Assets (Excluding Rural Households)	−0.024	0.138	−0.014	0.034	0.063	0.000
1.4 Total Retail Sales of Consumer Goods	0.040	0.047	0.001	0.030	–0.094	0.003
1.5 Total Sales of Commodities of Enterprises above Designated Size in Wholesale and Retail Trades	0.101	−0.116	0.024	0.035	−0.145	−0.043
1.6 Primary Industry as a Percentage to GDP	−0.015	0.025	−0.041	–0.297	–0.008	0.132
1.7 Secondary Industry as a Percentage to GDP	0.037	0.320	−0.057	0.135	–0.007	–0.530
1.8 Tertiary Industry as a Percentage to GDP	−0.013	−0.040	0.064	0.109	–0.010	0.445
2.1 Total population at Year-end	−0.018	0.162	−0.197	–0.014	0.089	–0.031
2.2 Number of Beds of Hospitals and Health Centers	0.037	0.100	−0.138	0.067	0.305	–0.024
2.3 Collections of Public Libraries per 100 persons	0.074	−0.042	0.126	0.318	–0.129	0.010
3.1 Persons Employed in Primary Industry	0.007	−0.146	0.024	0.098	0.194	–0.066
3.2 Persons Employed in Mining Industry	−0.024	0.195	0.134	–0.133	−0.117	0.224
3.3 Persons Employed in Manufacturing Industry	−0.028	0.457	0.019	–0.104	0.080	–0.025
3.4 Persons Employed in Construction Industry	0.195	0.524	0.040	–0.038	0.003	–0.042
3.5 Persons Employed in Real Estate	0.177	−0.117	0.020	–0.004	0.328	–0.010

(continued)

Table 134.2 (continued)

Items	Factor 1: integrated cities	Factor 2: industrial cities	Factor 3: transportation cities	Factor 4: Cultural and tourist cities	Factor 5: larger-scale cities	Factor 6: resource-dependent cities
3.6 Persons Employed in Traffic, Transport, Storage and Post	0.128	−0.037	0.356	–0.031	0.102	–0.048
3.7 Persons Employed in Catering and Business Services	0.125	−0.163	−0.001	0.012	–0.025	–0.058
4.1 total volume of transport	0.142	−0.050	0.210	0.080	0.002	–0.019
4.2 total volume of freight	0.083	0.043	−0.065	–0.036	–0.035	–0.027
4.3 Per Capita Area of Paved Roads in City	−0.101	0.108	−0.018	0.100	0.256	0.119
5.1 Per Capita Area of Green Land	−0.182	0.021	0.277	0.343	0.264	0.181
5.2 Area of Built-up Area Covered by Green	0.064	−0.031	0.300	–0.308	–0.009	–0.284
5.3 Volume of Industrial Waste Water Discharged	0.032	0.436	−0.092	–0.409	0.048	0.078

(5) The fifth factor was labeled “larger-scale cities”, as the load values of scale-related items (2.2, 3.5) on this factor is larger. (6) The sixth factor was labeled “resource-dependent cities”, as the load values of the resource-related item 3.2 on this factor is larger.

With the support of software SPSS 20.0, we categorized the 289 prefecture-level cities of China into six types by the method of clustering analysis (Table 134.3).

134.3.2 The Result of UGLC Estimation

The results of the UGLC estimation using the Eq. (134.1) are listed as follows in Table 134.4, which shows the per capita UGLC of the six types of cities from 2005 to 2014. In Fig. 134.1, we use a line chart to provide a visual interpretation of the per capita UGLC of the six types of cities from 2005 to 2014.

Table 134.4 and Fig. 134.1 show that the level of per capita UGLC in industrial cities, transportation Cities, larger-scale cities, and resource-dependent cities increased between 2005 and 2014, with the average annual growth rate of 7.16, 10.48, 3.62 and 7.22% respectively. Integrated cities is the most significant contributor to the increasing of UGLC among these six types of cities, which increased by 5.90 tons per capita in this period: from 8.34077×10^{-3} tons per capita in 2005 to 14.24290×10^{-3} tons per capita in 2014. The level of per capita UGLC in integrated cites is much larger than other five types of cities. Meanwhile, UGLC in cultural and tourist cities increased from 2.22569×10^{-3} tons per capita to 7.39556×10^{-3} tons per capita between 2005 and 2008, declined to 2.77142×10^{-3} tons per capita in 2009, and increased slowly in the following years. Furthermore, it can be seen that only the level of per capita UGLC in integrated cities is more than the national average.

134.4 Discussion

According to Table 134.4 and Fig. 134.1, it can be found there is significant difference in UGLC between the six types of cities. This difference can be explained by the different function of cities.

Integrated cities have a larger city-size, and its function is more comprehensive and special. Most of the integrated cities are metropolises such as Shanghai, Beijing and Guangzhou. Their special function includes providing International airport and subway service, high-tech development zones, research and education base, a large variety of public services, a variety of domestic and international offices, etc. It seems that achieving these functions necessarily use up a lot of land and the land used for greening is relative smaller. Actually, some of the integrated cities which are economic and political center put high value on green land which is important in beautifying the surroundings. For example, as an external window of China, Beijing

Table 134.3 The result of urban function classification

Integrated cities	Beijing, Guangzhou, Tianjin, Chongqing, Wuhan, Shenyang, Hangzhou, Xian, Chengdu, Nanjing, Kunming, Changchun, Xiamen, Taiyuan, Dalian, Changsha, Fuzhou, Lanzhou, Hefei, Qingdao, Foshan, Nanchang, Guiyang, Nanning, Ningbo, Tangshan, Huizhou, Yantai, Daqing, Zibo, Wuxi, Xuzhou, Anshan, Urumchi, Harbin, Shijiazhuang, Shanghai, Jinan, Zhengzhou, Shenzhen
Industrial cities	Suzhou, Laiwu, Anyang, Weihai, Yibin, Quanzhou, Leshan, Shaoxing, Wuhu, Loudi, Jiangmen, Xiangtan, Liaoyang, Heyuan, Jiaxing, Liuzhou, Deyang, Ezhou, Baoji, Taizhou, Weifang, Xuchang, Wenzhou, Yichang, Xinyu, Shanmenxia, Huzhou, Changzhou, Dezhou, Yueyang, Shanwei, Luzhou, Qingyuan, Yuxi, Zigong, Tonghua, Yangzhou, Xianyang, Rizhao, Qujing, Shiyan, Sanming, Neijiang, Linyi, Nanping, Baishan, Zhenjiang, Taizhou, Ziyang, Luoyang, Mianyang, Xiaogan, Zunyi, Jiayuguan, Songyuan, Baotou, Dongguan, Zhangjiakou, Tianshui, Shizuishan
Transportation cities	Xinyang, Dazhou, Nanyang, Cangzhou, Shaoyang, Chenzhou, Baoding, Hengyang, Yancheng, Zhoushan, Liuan, Jincheng, Xiangfan, Suzhou, Yongzhou, Fuyang, Yiyang, Dingxi
Cultural and tourist cities	Xining, Taian, Yinchuan, Liaocheng, Huangshan, Beihai, Guilin, Heze, Wuzhou, Linfen, Jiujiang, Huanggang, Langfang, Changzhi, Zhangzhou, Dandong, Chaozhou, Lijiang, Ganzhou, Jinzhong, Yingtan, Jinmen, Huaihua, Yanan, Hohhot, Hulunbeir, Tsitsihar, Lianyungang, Kiamusze, Zhangjiajie, Mudanjiang, Qinhaungdao, Haikou, Zhaoqing
larger-scale cities	Zhuhai, Sanya, Yulin, Qingyang, Fangchenggang, Heihe, Jiuquan, Shangluo, Hezhou, Hengshui, Guyuan, Bayannur, Lishui, Zhangye, Jian, Meizhou, Linchang, Yingkou, Guigang, Chengde, Tieling, Siping, Tongliao, Lvliang, Yaan, Anshun, Zhaotong, Yulin, Wuzhou, Bengbu, Baicheng, Wuwei, Laibin, Kaifeng, Zhongwei, Shangqiu, Bozhou, Suqian, Baise, Pingliang, Meishan, Hechi, Shangrao, Maoming, Chizhou, Zhumadian, Guangan, Hanzhong, Chaoyang, Congzuo, Chaohu, Jinzhou, Guangyuan, Huaian, Jilin, Chifeng, Xianning, Zhoukou, Puzhou, Ningde, Anqing, Suizhou, Weinan, Suining, Yichun, Xinxiang, Bazhong, Chuzhou, Jinzhou, Fuxin, Jinhua, Nanchong, Changde, Suozhou, Quzhou, Zhuzhou, Nantong, Chantou, Bijie, Tongren, Baoshan, Lasa, Lanzhou, Longnan, Wuzhong, Luohe, Binzhou, Dezhou, Jining, Puer, Jieyang, Yunfu, Yangjiang, Yuncheng
Resource-dependent cities	Handan, Xingtai, Yangquan, Wuhai, Fushun, Benxi, Panjin, Hulushan, Liaoyuan, Baishan, Jixi, Hegang, Shuangyashan, Qitaihe, Huinan, Maanshan, Huibei, Datong, Yuncheng, Xinzhou, Huangshi, Tongling, Zaozhuang, Dongying, Pingdingshan, Hebi, Jiaozuo, Puyang, Baiyin, Karamay, Tongchuan, Jjinchang, Panzhihua, Erdos, Wulamchabu, Liupanshui, Ankang

has took a lot of measures to increase the green of city which is a visualization of the city. So, the area of green land of integrated is larger, which lead Integrated cities is the most significant contributor to the increasing of UGLC among these six types of cities.

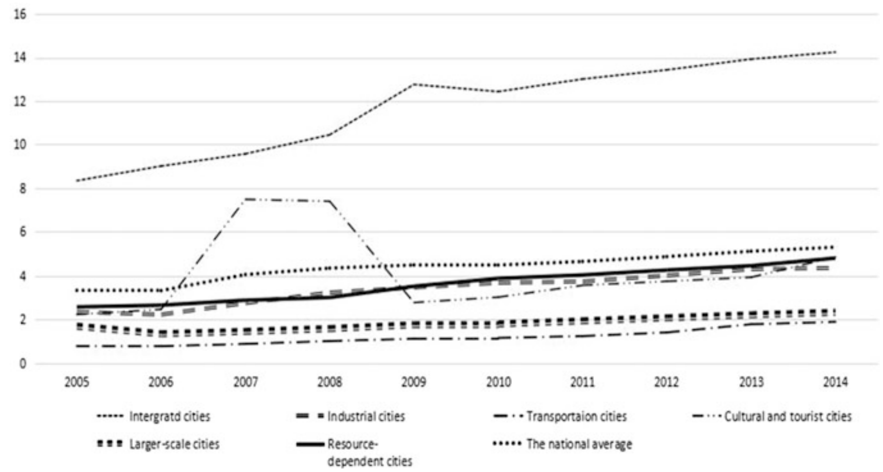

Fig. 134.1 The per capita UGLC of the six types of cities from 2005 to 2014

The function of industrial cities is producing various industrial products, so the most land of industrial cities is used for building large-scale factories, stacking industrial material, and internal transport. As a result, the land for green is relatively smaller, which lead to the level of per capita UGLC in industrial cities is lower. However, some industrial cities is adjusting industrial structure to promote the intensive utilization of land and pay higher attention on improving ecological environment by increasing green area, which lead to the level of per capita UGLC in industrial cities keep increasing year by year.

Transportation Cities have the functions of collecting and decentralizing of products, which is achieved by transportation system. These transportation systems consist of great transport facilities such as railroad, airport, port and dock, which cover a large area. As there is a trend that international trading will further develop, more land of transportation cities will be transform into storage land and be used for expanding the existing transportation system. So, the land of transportation cities used for green is more and more small, which lead to the level of per capita UGLC in transportation cities is lower for a long time.

Compered to integrated cities, the function of larger-scale cities is also comprehensive, but larger-scale cities are economic and political centers of smaller regions and integrated cities are economic and political centers of bigger regions. Another difference is that the economic strength of larger-scale cities is weaker and their influence is smaller. As shown in Table 134.4 and Fig. 134.1, the level of UGLC in larger-scale cities is much lower than that of integrated cities. Most of larger-scale cities developed from small country towns, so the local government pay more attention on city economic development than the urban planting, which contribute to the obvious difference in the level of UGLC in these two types cities.

Table 134.4 The per capita UGLC of the six types of cities

Year	Integrated cities ($\times 10^{-3}$ tons per capita)	Industrial cities ($\times 10^{-3}$ tons per capita)	Transportation cities ($\times 10^{-3}$ tons per capita)	Cultural and tourist cities ($\times 10^{-3}$ tons per capita)	Larger-scale cities ($\times 10^{-3}$ tons per capita)	Resource-dependent cities ($\times 10^{-3}$ tons per capita)	The national average ($\times 10^{-3}$ tons per capita)
2005	8.34077	2.34002	0.77028	2.22569	1.68967	2.56845	3.33109
2006	9.01033	2.22034	0.76843	2.45792	1.34376	2.64963	3.32024
2007	9.57357	2.74498	0.87015	7.48101	1.44906	2.87853	4.05826
2008	10.44734	3.23181	1.00492	7.39556	1.57774	3.00265	4.35268
2009	12.76053	3.46514	1.10864	2.77142	1.75466	3.52000	4.49766
2010	12.43161	3.67854	1.14643	3.01929	1.79170	3.880058	4.49394
2011	13.00665	3.73899	1.23191	3.56445	1.93473	4.03842	4.65903
2012	13.43050	4.01477	1.39878	3.74595	2.07457	4.26441	4.88300
2013	13.92357	4.30413	1.77580	3.93357	2.21120	4.461897	5.13009
2014	14.24290	4.36147	1.88442	4.86753	2.32677	4.81244	5.31619
The annual average rate of growth (%)	6.13	7.16	10.45	9.08	3.62	7.22	5.33

The foundation of the development of cultural and tourist cities is abundant tourism resources, so beauty spots of which the greening degree is higher occupied a lot of land. This may contribute to the higher level of UGLC in cultural and tourist cities. As shown in Table 134.4 and Fig. 134.1, the level of UGLC in cultural and tourist cities increased significantly in 2007 and 2008, because the area of green land of Tsitsihar which is one of cultural and tourist cities increased significantly in 2007 and 2008.

134.5 Conclusion

This study provides a functional classification of the 269 prefecture-level cities in China into six categories, including integrated cities, industrial cities, transportation cities, cultural and tourist cities, larger-scale cities, and resource-dependent cities. According to the analysis results, it can be found that there is significant difference in UGLC between the six types of cities. This difference can be explained by the different function of cities. It also demonstrates that integrated-type cities contribute far more to the national average value of UGLC. In addition, the increasing of the national average of UGLC year by year is also due to China's Eleventh Five-Year Plan (2005–2010) and Twelfth Five-Year Plan (2011–2015), which was designed to control and limit CO_2 emissions, increase green area and reform urban environment.

The findings of this study provide important references to the Chinese government for allocating the national emission reduction targets to various cities, of which the function determines the level of carbon sink. This study may lead the further research to explore how the ways of increasing urban carbon sink through improving the functions of different types of cities.

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