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Research Article

Energy-Related Carbon Emissions of China's Model Environmental Cities

Kevin Lo

Department of Resource Management and Geography, University of Melbourne, Melbourne, VIC 3010, Australia

Correspondence should be addressed to Kevin Lo; tslo@unimelb.edu.au

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This paper identifies three types of model environmental cities in China and examines their levels of energy-related carbon emissions using a bottom-up accounting system. Model environmental cities are identified as those that have been recently awarded official recognition from the central government for their efforts in environmental protection. The findings show that, on average, the Low-Carbon Cities have lower annual carbon emissions, carbon intensities, and per capita emissions than the Eco-Garden Cities and the Environmental Protection Cities. Compared internationally, the Eco-Garden Cities and the Environmental Protection Cities have per capita emissions that are similar to those of American cities whereas per capita emissions from the Low-Carbon Cities are similar to those of European cities. The result indicates that addressing climate change is not a priority for some model environmental cities. Policy changes are needed to prioritize climate mitigation in these cities, considering that climate change is a cross-cutting environmental issue with wide-ranging impact.

1. Introduction

Climate change is one of the most significant challenges facing the world today and cities are increasingly seen as key contributors to the issue. Urban activities, such as motorized transport, industrial production, electricity generation, domestic fuel use, and waste disposal generate significant amounts of greenhouse gases [1–3]. The International Energy Agency (IEA) forecasted that, by 2030, urban areas will account for 76% of global carbon emissions [4]. Thus, to prevent dangerous climate change, cities must bear some responsibility for reducing their impact on climate change and formulating effective responses [1, 5]. Inventorying urban carbon emissions is an important first step to address climate change effectively and fairly. Creating emissions inventories at the city level allows policymakers to identify the sources, establish baselines, monitor changes over time, make cross-comparisons with other localities, set appropriate emissions reduction targets, and formulate appropriate solutions [1]. The importance of inventorying urban carbon emissions is underscored by the large number of studies dedicated to such task [6–12].

China is critically important to the global effort of addressing climate change because of its enormous size of emissions [13]. Since 2006, the government has stepped up measures to promote energy conservation and renewable energy [14, 15]. Yet virtually no cities in China openly publish their greenhouse gases inventory on a regular basis. A number of studies have attempted to fill this gap. The calculation by Li et al. [16] showed that Shanghai's energy-related carbon emissions increased from 110 million tCO_2e in 1995 to 180 million tCO_2e in 2006. Wang et al. [17], also studying Shanghai, found that the city's total carbon emissions during 2000–2008 increased from 136 teragrams of CO_2e to 200 teragrams of CO_2e. In 2008, per capita emissions in Shanghai reached 14.03 tCO_2e, which were higher than both the world average and the average in China. Bi et al. [18] calculated that, in 2009, the total carbon emissions in Nanjing reached 75.43 million tCO_2e and per capital emissions reached 9.78 tCO_2e. Inventorying 12 Chinese cities, Wang et al. [19] found that carbon emissions in all cities rose from 2004 to 2008, but per capita emissions varied widely in different cities. Although China had lower-than-global-average per capita emissions (5.5 tCO_2e), the per capita emissions of many Chinese cities were greater than 8.0 tCO_2e, which were comparable to or even higher than those of many other cities in developed countries. Dhakal [20] approximated the energy-related emissions from 35 major cities using provincial carbon intensity data. The results showed that there were large differences in terms of per capita emissions within these cities, with the carbon-intensive cities largely located in the central and western parts of China, an area that attracted energy-intensive industries with low energy prices and favourable policies [21].

Building on these previous findings, this study aims to examine the levels of energy-related carbon emissions from China's model environmental cities, identified as those that have been recently awarded official recognition from the central government for their efforts in environmental protection. These cities are regarded as the leaders of environmental protection and sustainable development. However, concrete evidence on the environmental qualities of these cities in the present era of climate change has been lacking. As such, one may wonder whether and to what extent these cities are really environmentally friendly from the perspective of low-carbon urbanism. Following this introduction, this paper identifies three types of modelenvironmental cities. It then estimates the carbon emissions from these cities using annual emissions, annual per capita emissions, and carbon intensity. The paper concludes with a discussion of the policy implications of the results.

2. Three Types of Model Environmental Cities

This paper defines model environmental cities as cities that have received official recognition from the central government for their efforts in environmental protection. Although many cities in China declare their environmental credentials, cities that received official recognition have to go through quality assurance system and meet certain specified environmental standards. Therefore, they are considered as the leaders in China with respect to environmental issues. There are three types of model environmental cities: Eco-Garden Cities, Environmental Protection Cities, and Low-Carbon Cities. The remaining portion of this section will examine these different types of model environmental cities more closely.

2.1. Eco-Garden Cities. The Eco-Garden City Program was established in 2004 by the Ministry of Construction (now the Ministry of Housing and Urban-Rural Development [MOHURD]). The aim of the program is to award recognition to cities that protect and improve the health of urban ecosystems. Eco-Garden Cities are required to work toward a number of objectives, including construction and maintenance of parkland, improving access for pedestrian and bicyclist, urban greening, improving public transport, increasing the density of developed areas, protection of ecosystems, increasing the proportion of energy-efficient buildings, and increasing the deployment of renewable energy. The MOHURD developed a complicated system of 90 quantitative targets to guide local governments toward the achievement of these objectives. For example, one of the energy and climate targets is to achieve at least 60% coverage by public transportation. Because not every target is compulsory, an Eco-Garden City may fail to meet one or more of the criteria.

A city aspiring to be an Eco-Garden City must first establish an action plan to achieve the specified targets and then must implement the plan for at least three years. The city is then evaluated, first by the Department of Housing and Urban-Rural Development at the provincial-level and then by the MOHURD. The assessment process involves independent surveys, remote-sensing analysis, field inspections, and expert evaluations. A city that passes the assessment earns the right to call itself an Eco-Garden City. However, an Eco-Garden City that is later found to be noncompliant with the requirements would be either cautioned or disqualified, depending on the degree, scale, and nature of the infringement.

2.2. Environmental Protection Cities. In 1997, the Environmental Protection Bureau (now the Ministry of Environmental Protection [MEP]) established the Environmental Protection City Program to encourage cities to improve environmental quality through sustainable development. Environmental Protection Cities are required to work toward a number of environmental objectives, including air pollution prevention, water pollution prevention, improving waste management, reducing industrial energy intensity, and increasing the deployment of renewable energy use. The MEP developed 22 quantitative targets for Environmental Protection Cities. All of the targets are compulsory, unlike those of the Eco-Garden City Program. There are two targets relevant to climate change. First, industrial energy intensity must be less than the national average. Second, more than 50% of the energy used must come from sources other than coal.

A city aspiring to be an Environmental Protection City must first prepare a proposal demonstrating concrete plans to meet the specified targets and then submit the proposal to the provincial Environmental Protection Bureau for approval. The city must then implement the proposal and later submit a detailed report on how the criteria have been met. The MEP then assembles a team of experts to evaluate the application. The application is immediately rejected if more than two targets have not been met. However, if only one or two targets are not met, the city is given three months to meet the targets. A program revision in 2011 introduced a five-year lifecycle for the program, under which the Environmental Protection City status automatically expires after five years unless the city reapplies successfully.

2.3. Low-Carbon Cities. The National Development and Reform Commission (NDRC) established the Low-Carbon City Pilot Program in 2010 as a key climate change response. The NDRC is a powerful ministry in the central government. It is responsible for planning the economic development of the country and has been designated as the ministry with primary responsibility for energy and climate change. Participating local governments are encouraged to go beyond mere compliance with existing low-carbon policies and programs. The specific obligations and commitments include developing a long-term low-carbon development plan, implementing institutional reform and effective policy instruments to lower carbon emissions, developing low-carbon industries, buildings and transportation, developing carbon emissions accounting and management systems, and promoting low-carbon lifestyles and consumption. The NDRC has yet to release quantified targets for these obligations. The NDRC has promised to provide venues for information exchange and policy learning to help cities achieve their objectives.

2.4. Studied Cities. At the time of writing, there were 12 Eco-Garden Cities, among them, 9 were prefecture-level cities (Guilin, Yangzhou, Nanjing, Suzhou, Qingdao, Weihai, Jincheng, Hangzhou, and Shaoxing), and 3 were county-level cities. There were 22 Environmental Protection Model cities; among them 14 were prefecture-level cities (Dongguan, Foshan, Zhongshan, Langfang, Daqing, Yichang, Zhenjiang, Xuzhou, Huaian, Yinchuan, Liaocheng, Linyi, Weihai, and Shaoxing). There were 8 cities in the Low-Carbon Cities Pilot Program and 6 of them were prefecture-level cities (Xiamen, Shenzhen, Guiyang, Baoding, Nanchang, and Hangzhou) and 2 were provincial-level cities (Chongqing and Tianjin). Because of overlaps and the lack of accessibility to statistical yearbooks in some cities, in total, there are 15 cities that serve as the dataset for this study. Figure 1 displays the locations of the studied cities.

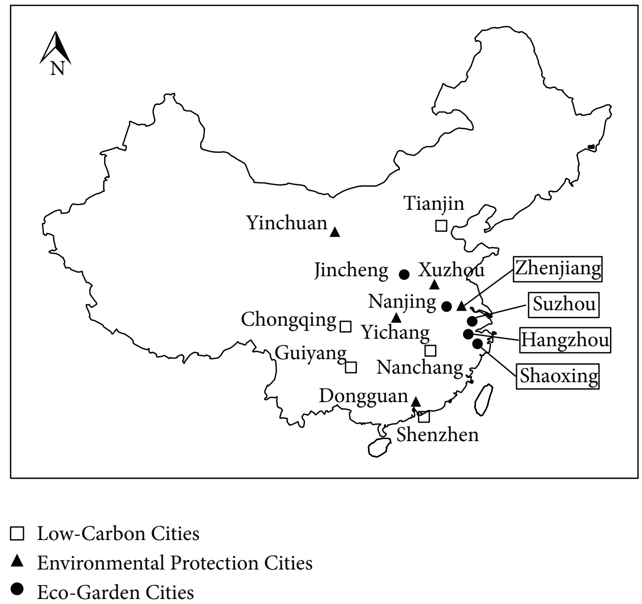

Figure 1: The locations of the studied cities.

3. Methods

The present study uses a bottom-up accounting system to measure carbon emissions from stationary and mobile sources at the municipal level. It first calculates stationary emissions from the combustion of primary energy sources (e.g., coal and gasoline). The inventory is then modified because a city may import or export electricity. Emissions from a net export of electricity are deducted from the inventory, and emissions associated with a net import of electricity are added to the inventory. The formula for stationary emissions is

$$\mathrm{GHG} = \left(\sum_{i,j} E_{i,j} C_j \right) + (I - X) C_e, \quad (1)$$

where GHG is the total stationary emissions in tons; i represents subsectors (e.g., textile or steel making); j represents the energy type (e.g., coal or crude oil); $E_{i,j}$ is the energy consumption per subsector and energy type; C_j is the CO_2 emission factor for specific energy types; I is the quantity of electricity imported into the city; X is the quantity of exported electricity; and C_e is the CO_2 emission factor for electricity.

With regard to mobile emissions, this study only calculates emissions from road transportation because of a lack of data from air, water, and rail transportation. Air, water, and rail transportation is also usually cross-boundary, and it is therefore difficult to attribute their emissions to a particular city. This study distinguishes five modes of road transport: taxis, public buses, other passenger vehicles, trucks, and motorcycles. Each mode of transport has its own unique annual mileage and emission factors. Emissions from road transport are calculated using the following equation:

$$\mathrm{GHG} = \sum_i P_i \times D_i \times C_g, \quad (2)$$

where GHG is carbon emissions from road transportation; i is the mode of transport (e.g., taxis or passenger cars); P_i is the number of vehicles in each mode of transportation; D_i is the annual mileage of a type-i vehicle measured in km; and C_g is the CO_2 emission factor measured in ton/km.

Data describing industrial energy consumption; import and export of electricity; numbers of taxis, buses, passenger vehicles, trucks, and motorcycles; GDP; and population are collected from the 2011 statistical yearbook for each municipality [22–36]. Some of the statistical yearbooks do not contain information about export and import of electricity, in which case the import/export data are estimated from the provincial-level electricity balance table that is in the China Energy Statistical Yearbook [37]. Carbon emission factors are obtain from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1) [38]. Carbon emission factors for electricity are acquired from Wang et al. [39], who calculated the emission factors in China's six large national power grids using electricity generation fuel mixes and power exchange data (Table 2). Average annual mileage and average gasoline consumption for different modes of transportation are collected from Loo and Li [3] (Table 3).

This study focuses on energy-related emissions because the data are mostly complete and reliable. Three types of emissions are not calculated in this study, including emissions from agriculture, forest management, and other land uses

Table 1: Emission factors for combustion of fuel.

Fuel	CO_2 emission factor (kg/TJ)	Fuel	CO_2 emission factor (kg/TJ)
Crude oil	73,300	Natural gas	56,100
Gasoline	74,100	Other petroleum products	73,300
Kerosene	71,500	Raw coal	97,500
Fuel oil	77,400	Washed coal	94,600
Diesel oil	74,100	Other types of washed coal	94,600
Coke oven gas	44,400	Coke	107,000
LPG	63,100		

Table 2: Emission factors of six major power grids.

Grid	CO_2 emission factor (ton/million kWh)	Grid	CO_2 emission factor (ton/million kWh)
Northeast China	871	East China	688
North China	874	Northwest China	701
Central China	555	South China	552

Table 3: Average annual mileage and average gasoline consumption different modes of transportation.

	Taxis	City buses	Private cars and institutional vehicles	Motorcycles
Average annual mileage (km)	71,175	34,000	18,000	10,000
Average gasoline consumption (km/kg)	15.07	3.91	15.07	50.23

(AFOLU), such as CO_2 from deforestation, CH_4 from enteric fermentation and manure, and N_2O from fertilizer use, landfill gases, mainly CH_4, and emissions from industrial processes, such as CO_2 and perfluorocarbon emissions from aluminum smelting and N_2O emissions from the production of nitric acid. These omissions result in an underestimation of the emissions inventories, although not by a significant amount, because energy consumption is the dominant source of carbon emissions in Chinese cities, typically responsible for over 90% of the total emissions [40].

4. Results

Annual carbon emissions, annual per capita carbon emissions, and carbon intensity of the studied cities are calculated using the methods and data described above. Per capita emissions and carbon intensity are used to facilitate comparisons among the cities, which vary widely in population size and state of economic development. Per capita emissions are calculated by dividing annual emissions by the total population of the city in question. Carbon intensity expresses the emissions generated in the production of 10,000 RMB worth of GDP and is calculated by dividing annual emissions by annual GDP. The results are shown in Figures 2, 3, and 4.

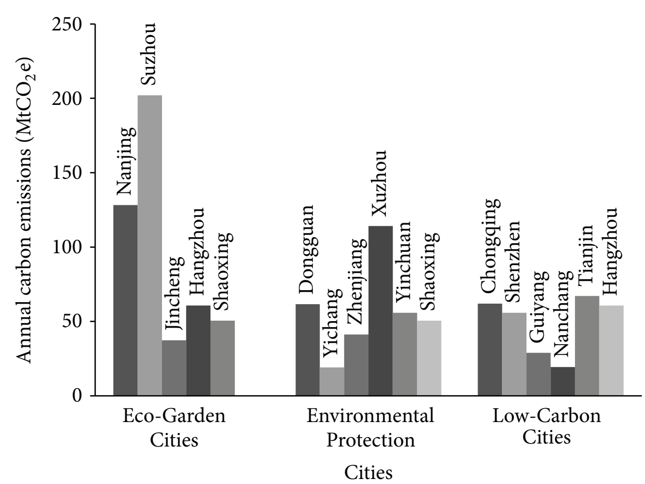

Figure 2: Annual carbon emissions from the model environmental cities.

On average, the Eco-Garden Cities emit far more CO_2 (mean = 95,771,862 tCO_2e) than both the Environmental Protection Cities (mean = 57,102,423 tCO_2e) and the Low-Carbon Cities (mean = 48,991,821 tCO_2e). However, there are significant differences within each group according to the size and economic activity of the city. Nanjing (an Eco-Garden City), Suzhou (an Eco-Garden City), and Xuzhou (an Environmental Protection City), which produce more emissions than any other city in this study, are all located in Jiangsu, one of China's most heavily industrialized area. Yichang, an Environmental Protection City, and Nancheng, a Low-Carbon City, have the lowest levels of emissions. Both of these cities are small-sized cities in inland China.

The Environmental Protection Cities have the highest average carbon intensity (mean = 3.34 tCO_2/10000 RMB), followed by the Eco-Garden Cities (mean = 2.54 tCO_2/10000 RMB) and the Low-Carbon Cities (mean = 1.09 tCO_2/10000 RMB). The most carbon-intensive city is Yinchuan, a coal-dominated Environmental Protection City in the northwest. The least carbon-intensive city is Shenzhen, a wealthy and postindustrial Low-Carbon City in the Pearl River Delta area.

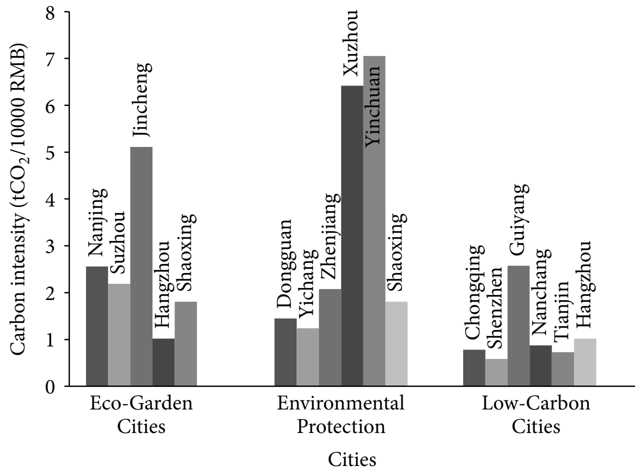

Figure 3: Carbon intensity of the model environmental cities.

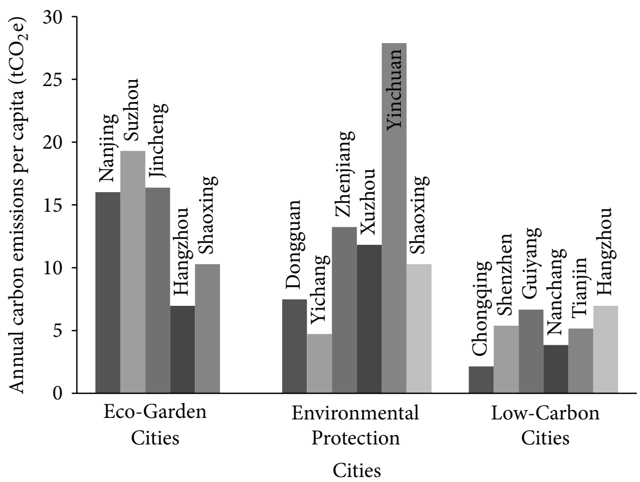

Figure 4: Annual carbon emissions per capita from the model environmental cities.

The Low-Carbon Cities have on average substantially lower per capita emissions (mean = 5.03 tCO_2e) than both the Eco-Garden Cities (mean = 13.79 tCO_2e) and the Environmental Protection Cities (mean = 12.58 tCO_2e). Yinchuan is the city with the highest per capita emissions, and, Chongqing, a Low-Carbon City in inland China, has the lowest. Compared internationally, the Eco-Garden Cities and the Environmental Protection Cities have per capita emissions that are similar to American cities, such as Boston (12.23 tCO_2e, 2009 data) and Seattle (11.47 tCO_2e, 2008 data) [41] whereas the levels of per capita emissions from the Low-Carbon Cities are similar to those of European cities, such as Berlin (5.86 tCO_2e, 2007 data) and London (5.98 tCO_2e, 2008 data) [41].

5. Discussion and Conclusion

The analysis has shown that, on average, the Low-Carbon Cities have lower annual carbon emissions, carbon intensities, and per capita emissions than the Eco-Garden Cities and the Environmental Protection Cities. This reflects the different goals and priorities of the model environmental cities, which are influenced by the programs that award official designations. The Low-Carbon City Program focuses on climate change, and all participating cities are required to implement a number of climate mitigation measures. All Low-Carbon Cities have therefore formulated climate change action plans and committed themselves to carbon intensity targets. Some cities, such as Hangzhou and Nanchang, have announced targets that are more ambitious than the national commitment of reducing carbon intensity by 40–45% of 2005 levels by 2020. Low-Carbon City climate change action plans are usually comprehensive, covering emissions from key sectors, including industry, energy, housing, and transportation. For example, Shenzhen will develop new industries in alternative energy, information technology, biotechnology, new materials, cultural industry, and energy conservation services, promote the deployment of natural gas, nuclear power, and solar energy, and introduce compulsory solar water heating for buildings less than 12 stories in height [42]. Shenzhen is currently the most successful city in the promotion of electric vehicles. The city launched the world's largest green taxi fleet of 300 electric-only vehicles in 2010 and plans to build 250 charging stations and install 12,500 charging posts in the city.

In contrast, climate change is not a focus of the Eco-Garden City Program and the Environmental Protection Program. The Eco-Garden City Program focuses primarily on protecting the health of urban ecosystems. The Environmental Protection City Program concentrates on air and water pollution and waste management. Both programs incorporate the concept of sustainable development and therefore emphasize a broad range of issues, such as economic and social development and environmental quality. While these two programs have energy and climate objectives, such objectives are too narrow and not sufficiently demanding. Furthermore, the objectives can be ignored completely in the Eco-Garden City Program because they are not compulsory. Therefore, the Eco-Garden Cities and the Environmental Protection Cities have, in general, failed to pay sufficient attention to climate mitigation.

Climate change is a cross-cutting issue that impacts a wide range of economic, social, and environmental aspects of cities. Climate change exacerbates urban heat island effects [43, 44], increases the frequency of flooding due to rising sea levels, leads to more frequent and severe extreme weather events [45], and exacerbates water security problems by changing the amount, variability, timing, form, and intensity of precipitation [46]. For these reasons, climate change mitigation should be made a priority for all types of model environmental cities in China, not just the Low-Carbon Cities. This can be achieved by reforming the Eco-Garden City Program and the Environmental Protection City Program to incorporate more climate-related objectives. These climate objectives should be comprehensive, covering emissions from the industry, building, and transportation sectors, and be sufficiently challenging to motivate cities to experiment with different climate mitigation policies.

Conflict of Interests

The author declares that there is no conflict of interests regarding the publication of this paper.

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