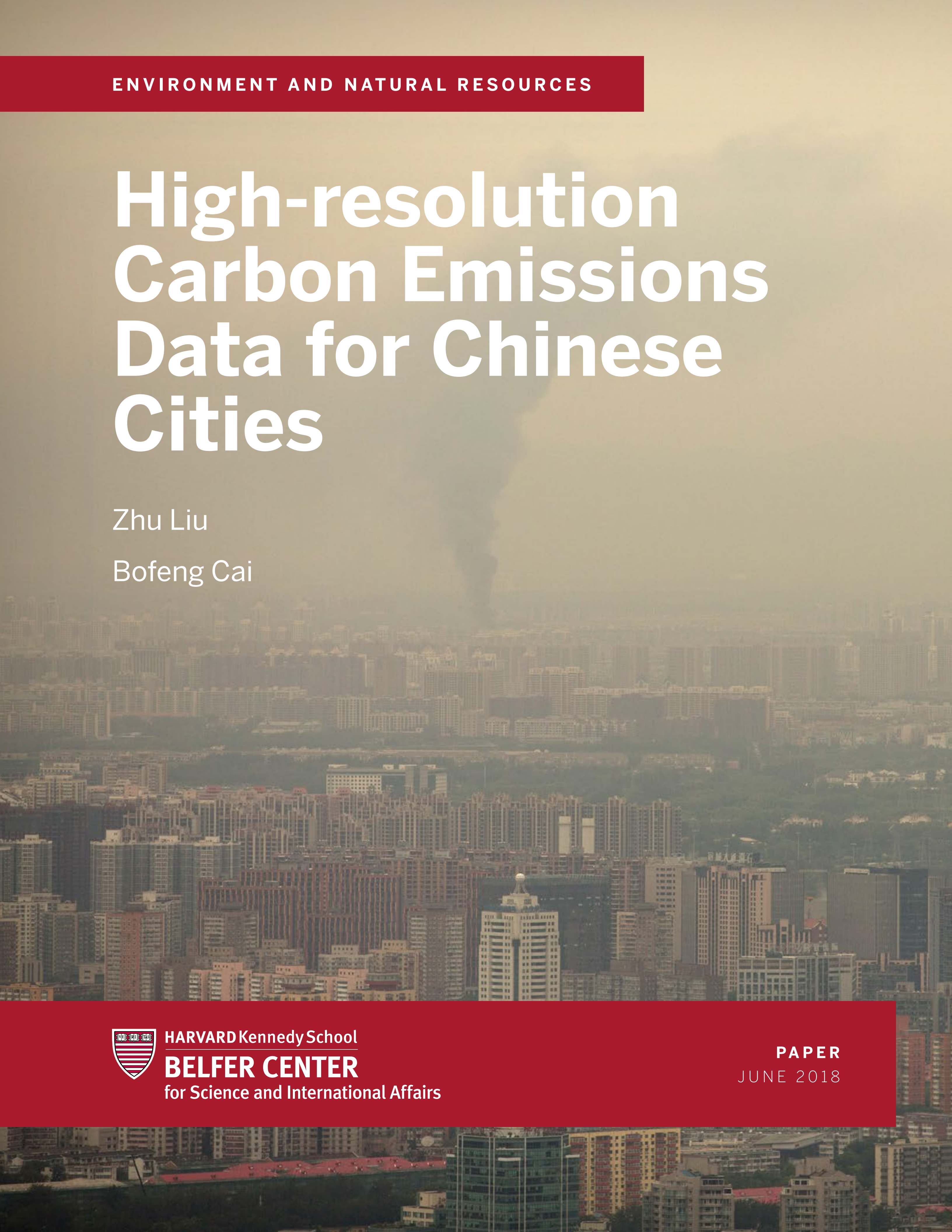

ENVIRONMENT AND NATURAL RESOURCES

High-resolution Carbon Emissions Data for Chinese Cities

Zhu Liu

Bofeng Cai

HARVARD Kennedy School
BELFER CENTER
for Science and International Affairs

PAPER
JUNE 2018

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Cover photo: Smoke rises above the skyline of Beijing on a moderately polluted day, Saturday, Aug. 26, 2017. (AP Photo/Mark Schiefelbein)

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About the Project

The Environment and Natural Resources Program at the Belfer Center for Science and International Affairs is at the center of the Harvard Kennedy School's research and outreach on public policy that affects global environment quality and natural resource management. Its mandate is to conduct policy-relevant research at the regional, national, international, and global level, and through its outreach initiatives to make its products available to decision-makers, scholars, and interested citizens.

More information can be found on ENRP's web site at www.belfercenter.org/enrp or from assistant director, Amanda Sardonis (amanda_sardonis@hks.harvard.edu) at ENRP, Harvard Kennedy School, 79 JFK Street, Cambridge, MA 02138 USA.

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Dr. **Zhu Liu** is an Associate at the Environment and Natural Resources Program at the Belfer Center for Science and International Affairs. His research focuses on global sustainability accounting and low carbon energy transition. Zhu is contributing to collaborative work with the Initiative on Sustainable Energy Development in China led by Senior Lecturer in Public Policy Henry Lee. He conducted his Doctoral study in Ecology at the Chinese Academy of Sciences (CAS) and graduated with CAS highest honor (CAS Presidential Special Award). Zhu received his Ph.D. from CAS (2013) with joint training by the University of Cambridge (2012). He holds a Bachelor's degree in Geology from Northwest University (2007) and a Master's degree in Ecology from China Agricultural University (2009). His research on energy and climate has been published in Nature, Nature Climate Change, PNAS, and other professional journals.

Dr. **Bofeng Cai** has special expertise in the GHG emissions inventory of energy use, Industrial Processes and Product Use (IPPU) and landfill, waste water treatment, etc. He was one of the Lead Authors of IPCC 2013 Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol in 2012, and one of the Coordinating Lead Author (CLA) of IPCC 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Dr. Cai is mainly focused on city carbon emissions and high-resolution carbon dioxide emission gridded data of China.

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Cover Image
Smoke rises above the skyline of Beijing on a moderately polluted day, Saturday, Aug. 26, 2017. (AP Photo/Mark Schiefelbein)

Executive Summary

China is currently the world's largest energy consumer and CO_2 emitter, and its cities contribute 85% of the total CO_2 emissions in China. Given the magnitude and growth rate of Chinese cities' carbon emissions, cities are considered to be the key areas for implementing policies designed to adapt to climate change and mitigate CO_2 emissions.

In this research, we used high-resolution CO_2 emissions data (data from China High-Resolution Emission Gridded Database (CHRED) at 1 km spatial resolution) from 288 Chinese cities. There were, in total, 9,723 million metric tons (MMT) CO_2 produced in 2012 from the 288 cities. The results show that the 288 cities had variable per capita emissions and emission intensities; both low-carbon and carbon intensive cities exist in urban China. The CO_2 per capita for these 288 cities was 11 tCO_2/person, which is lower than the US average, but higher than that of the European Union. The per capita CO_2 emissions were weakly related with the per capita GDP in the 288 cities, indicating that there was no environmental Kuznets pattern for the carbon emissions related to a city's level of economic development in China. The research implies that urbanization may be low-carbon or carbon intensive for China. Thus, promoting a low-carbon transition for Chinese cities is critical for global greenhouse gas mitigation.

1. Background of CO_2 emissions data from Chinese cities

The urbanization process in China and technology developments in the United States are considered to be the main forces shaping the world in the 21st century. City development is the major driver of China's economy, with 50% of China's GDP growth in the past 10 years contributed by infrastructure investments associated with the urbanization process. Presently, cities account for 75% of China's total GDP and 80% of its national energy consumption. The urbanization rate in China is expected to reach 75% in 2030, which is considered by some scholars to be the main driving force for China's leadership in the world, after the United States, in terms of total economic volume. Urbanization in China reallocated approximately 200 million people into urban areas, and these processes are expected to relocate more than 300 million people to China's cities over the next 15 years. Nearly 70% of the population will live in urban areas by 2035. It is expected that in the next 20 years, China will build approximately 50,000 new skyscrapers in its urban areas, which will require considerable infrastructure development and energy consumption in urban China.

The urbanization process in China is critical for protecting the global environment. China has already become the world's top fossil fuel energy consumer and CO_2 emitter and has performed intensive studies on the features, characteristics and driving factors of its carbon emissions and mitigation actions. As the world's largest developing country, with unprecedented urbanization, industrialization and poverty elimination processes, China has been and will continue to be the major force behind anthropogenic carbon emissions and their mitigation.

Concrete emission inventories are considered to be the cornerstone for emissions research and mitigation strategies for cities. However, challenges remain in regard to presenting comprehensive carbon emission inventories at the city level; to measuring, reporting and verifying inventories; and to minimizing the associated uncertainties. This is particularly difficult in a large country with significant geographical and social-economic diversity, such as China, because producing comprehensive carbon emission inventories requires very detailed carbon accounting for each city as well as a comprehensive understanding of local climate strategies. The methodology and associated inventories for CO_2 emissions have been developed at the national scale. Compared with nation states, cities have various definitions regarding their boundaries and non-centralized statistics as well as large discrepancies regarding the definitions of their economic development levels, which produce uncertainty for carbon emissions accounting, especially in developing countries, such as China. For example, in China, the city is the second level of an administration area (the province is the first level) and not only includes urban areas but also vast rural areas; there are 286 administration cities in China. Thus, the administrative boundary of a Chinese city is larger than that of a city in developed countries, where only urban areas are included in a city's boundary.

In addition, cities have various definitions of the boundaries regarding emissions accounting and non-centralized statistics as well as large discrepancies in regard to defining the levels of economic development, producing uncertainty for carbon emission accounting. System scope boundaries significantly affect regional emission inventories. Researchers have generally assumed a closed system boundary when conducting regional emission inventories; however, the reality is that regions have intensive interactions across calculated boundaries (administrative boundaries), such as domestic and international transportation and purchased power supply, (generated outside the boundary). These cross-boundary activities can dramatically affect emission estimates and the distribution of associated mitigation responsibilities. The academic literature has defined the territorial direct emission boundary as scope 1, the boundary of the emission caused by purchased electricity produced outside the boundary as scope 2, and the boundary of the emission embodied in imported products and services as scope 3. By further balancing the emissions embodied in imports and exports, the emission inventory boundary, which is considered to be the emissions embodied in imports but to exclude that of exports, is defined as consumption emissions. Whether such embodied emissions are taken into account will dramatically affect the emissions inventory at the city level.

Finally, but most importantly, as a developing country, China's statistics system is not as comprehensive as that of developed countries. Regional statistics have comparatively more uncertainty than those at the national level and lack sectoral information, making it more difficult to conduct China's cities' CO_2 inventories. There are a few main studies that have conducted a "bottom-up" (see methods) CO_2 emission inventory in Chinese cities; however the number of studies and sectoral information is limited.

High-resolution emission data contribute to solving such challenges. Carbon accounting from high-resolution emission data is a key research direction in the field of climate change. There is a focus on analyzing the extent, as well as the causes and effects, of CO_2 emissions at a fine scale. Understanding emissions at the city and regional levels according to high spatial resolution CO_2 emissions data has been highlighted in the carbon management literature.

In this study, we established a comprehensive and systematic city-level CO_2 emission data system in China based on the China High-Resolution Emission Gridded Database (CHRED) (1 km spatial resolution), and we further analyzed the characteristics of the total and per capita city emissions. We focused on prefecture-level cities and municipalities that are directly under China's central government. According to the "2013 China Statistical Yearbook", there were 285 prefecture-level cities and 4 municipalities in China in 2012. The CHRED database does not include Sansha City (founded in 2012). Therefore, this study included 288 cities covering 284 prefecture-level cities and 4 municipalities.

2. Data Sources

We considered CO_2 emissions from scope 1 (direct) and scope 2 (indirect emissions from imported electricity), and the direct CO_2 emissions data of cities were derived from CHRED (see the methodology section for details). CHRED was developed for China using a bottom-up approach based on point emission sources and other supporting data. CHRED 2.0 provides a 1 km gridded dataset of CO_2 emissions in China during 2012 (Figure 1). Detailed information on CHRED can be found at http://www.cityghg.com/ and in previous publications (Cai et al. 2016; Cai & Zhang, 2014; Wang et al. 2014).

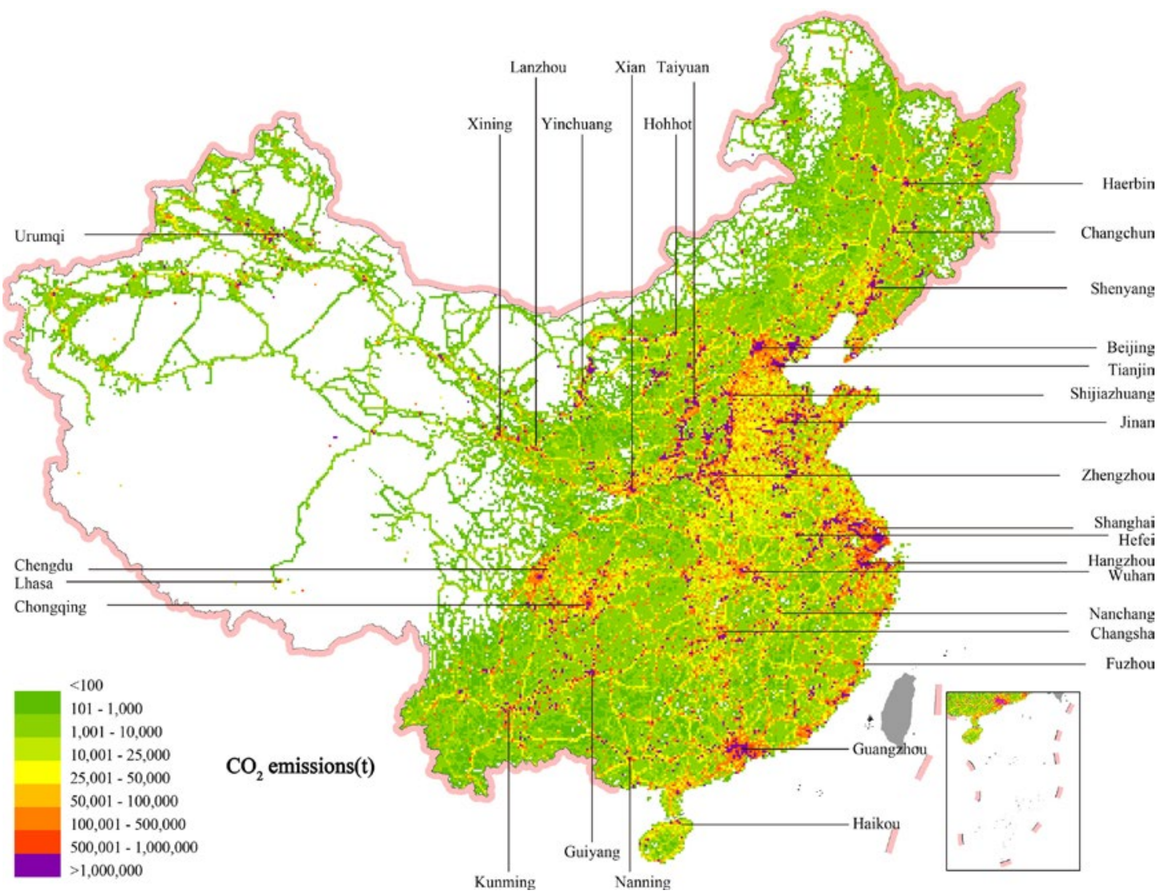

Figure 1. Spatial map of CO_2 emissions in China in 2012

The indirect emissions of a city are calculated by multiplying the volume of imported electricity by the emission factor of the city (see the methodology section for details). Electricity generation data from fossil fuel power plants for each city were obtained from CHRED. Data regarding electricity generation from non-fossil fuel power plants for each city were from the 2012 Power Industry Statistics (China Electricity Council, 2016). Total electricity consumption data for each city were obtained from the China City Statistical Yearbook (Department of Urban Socioeconomic Investigation, 2014).

3. Results

Calculating the carbon emissions from 288 Chinese cities (Figure 2) based on the bottom-up carbon emission inventories, the total emissions from 288 cities is 9,723 MMT CO_2 for administrative boundary scope 1 emissions and 933 MMT CO_2 for scope 2 emissions. The aggregated CO_2 emissions from 288 cities is even higher than the total emissions from the United States (the second largest emitter) and is equivalent to China's total carbon emissions. The results show that 288 cities have varied per capita emissions and emission intensities. Cities could have high levels of emissions per capita and low levels of GDP per capita, and vice versa. The results indicate that both low-carbon and carbon-intensive pathways exist in China's urbanization process. The per capita CO_2 is not related to the per capita GDP.

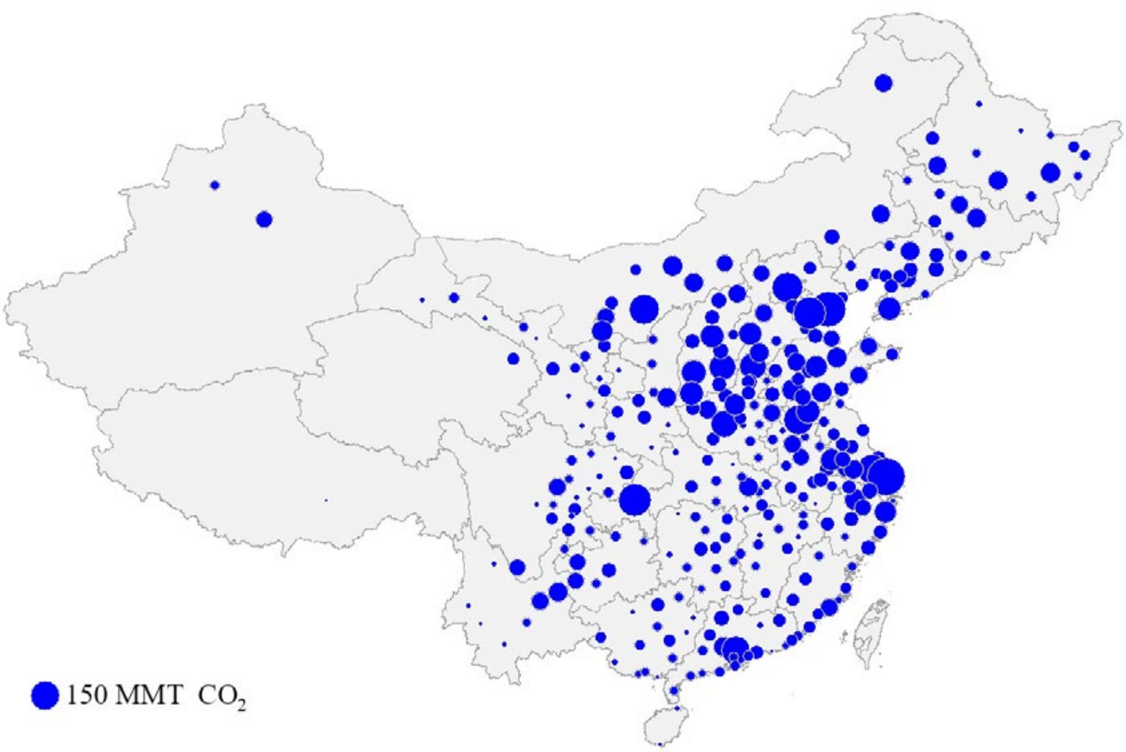

Figure 2. CO_2 emissions from 288 Chinese Cities

The majority of cities (272 cities, 94%) have emissions below 100 MMT, and most cities (223 cities, 77%) have emissions below 50 MMT (Figure 3). There are 37 cities with emissions below 10 MMT. Two cities, Shanghai and Tangshan, have emissions exceeding 200 MMT. Nineteen cities have emissions of over 100 MMT. Most cities have emissions ranging between 15 and 20 MMT.

On average, the CO_2 emissions of Chinese cities were approximately 36 MMT in 2012. Cities with high CO_2 emissions are generally located in the north, northeast and coastal areas of China (Figure 4). For example, the cities with the highest CO_2 emissions are Beijing, Tianjin, Tangshan, Ordos, Shanghai and Suzhou, which exceeded 150 MMT annually in 2012. Low CO_2 emission cities are generally located in less developed regions, such as the south, southwest and northwest of China. The exception is Chongqing, which emits 192 MMT CO_2, ranking as the third highest CO_2 emitter in China.

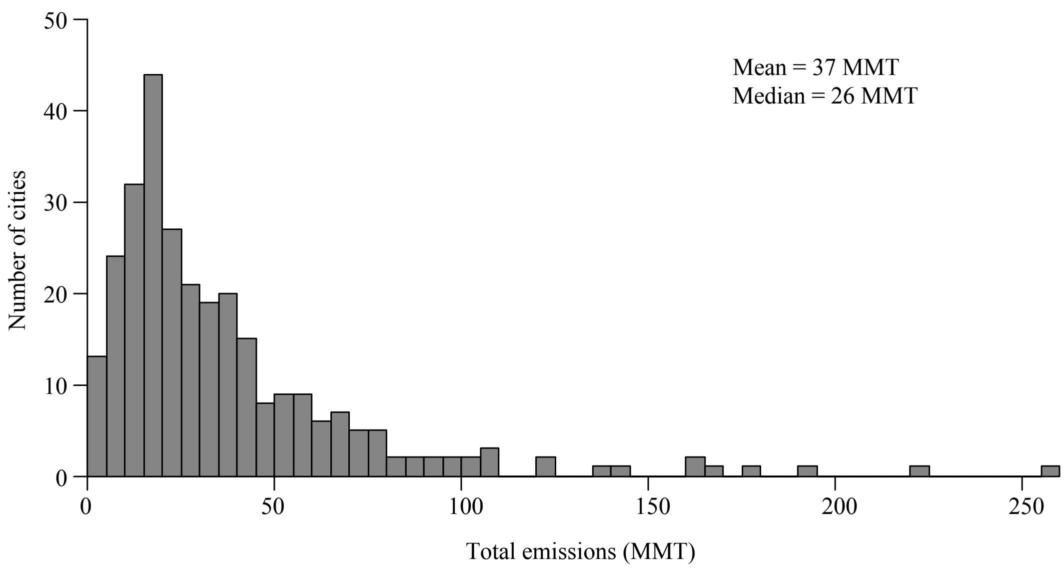

Figure 3. Histogram of the total emissions of cities

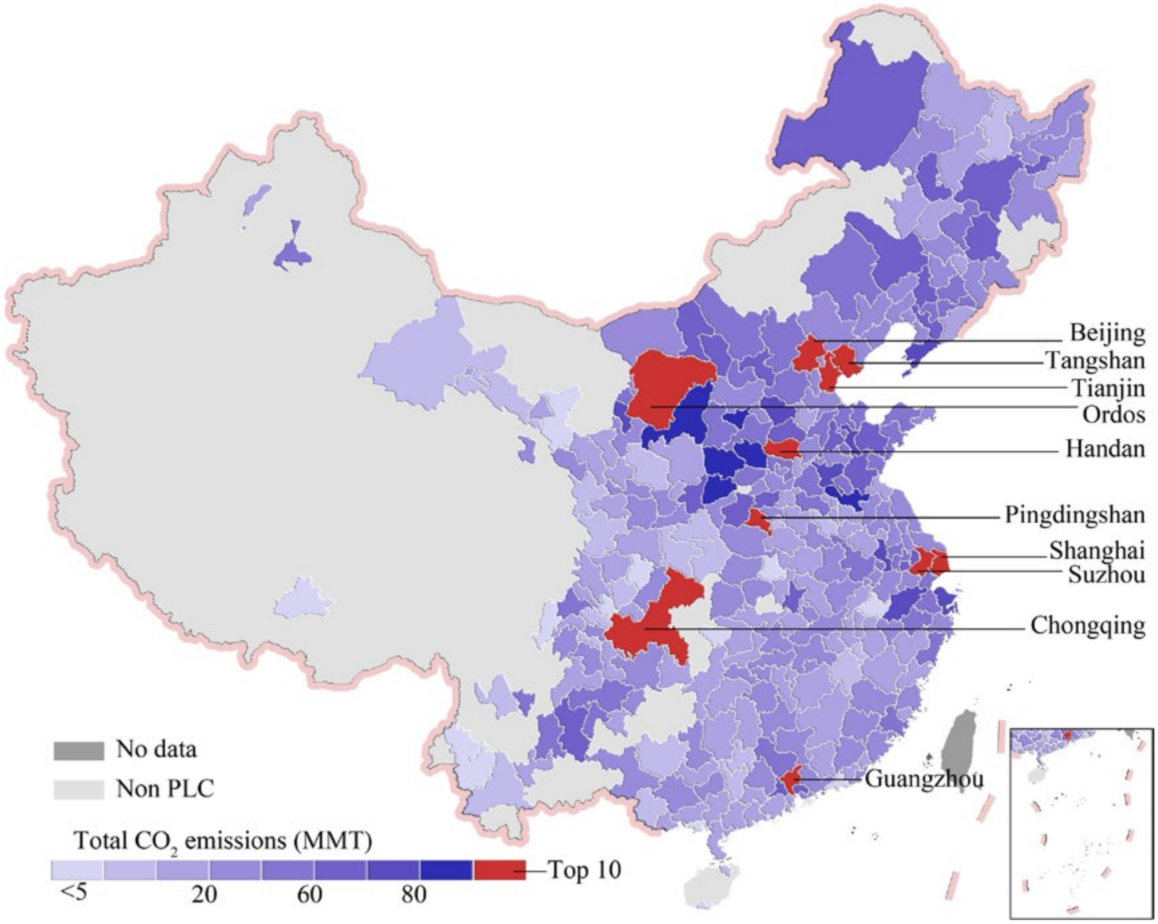

Figure 4. Distribution of city CO_2 emissions and the top ten CO_2 emitting cities in China

Note: PLC refers to prefecture level cities.

For emissions per capita (Figure 5), the overall shape of the histogram of the cities' per capita CO_2 emissions is positively skewed to the right. The majority of cities (255, 89%) have values < 20 t/person. Five cities have values > 50 t/person. Ninety-nine cities have values > 10 t/person. Ninety-six cities have values < 5 t/person. The mean is 11 t/person. Cities with values > 50 t/person are all resource-based industrial cities. There is a large gap between the highest and lowest per capita values, which is closely related to the economic disparities among cities.

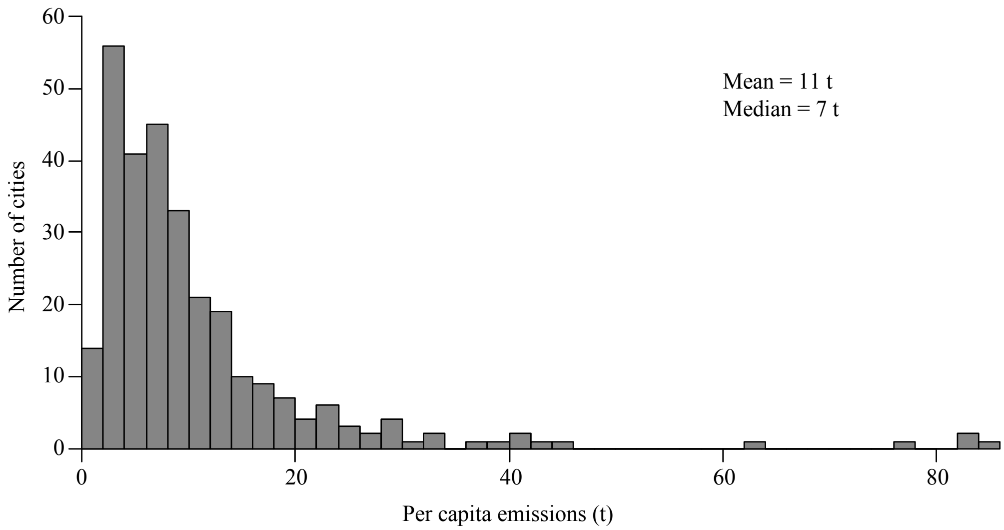

Figure 5. Histogram of the per capita emissions of cities

The per capita CO_2 emissions of cities in the north are larger than those of cities in the south, and the spatial aggregation of cities with high per capita emissions is more obvious in the north (Figure 6). The majority of cities with higher per capita CO_2 emissions are distributed in north and northeast China. There are many cities with higher per capita CO_2 emissions in the Inner Mongolia Autonomous Region and Shanxi Province. In comparison, city per capita CO_2 emissions are not high in the Yangtze River Delta and Pearl River Delta regions, which are economically more developed. The cities with the largest per capita CO_2 emissions are mostly rich in coal or other natural resources. These cities heavily rely on natural resources and have simple energy and industrial structures and a higher ratio of secondary industries. Erdos, Wuhai, Shizuishan, and Yinchuan, the four cities clustered among the top ten in per capita CO_2 emissions, are all in primary coal production areas of China, which demonstrates the important impact of coal resources on the city industrial structure and CO_2 emissions. In the south, the higher per capita CO_2 emissions of Tongling City result from its copper and cement industries. The iron and steel industries are the major reason for the high per capita CO_2 emissions in Panzhihua City.

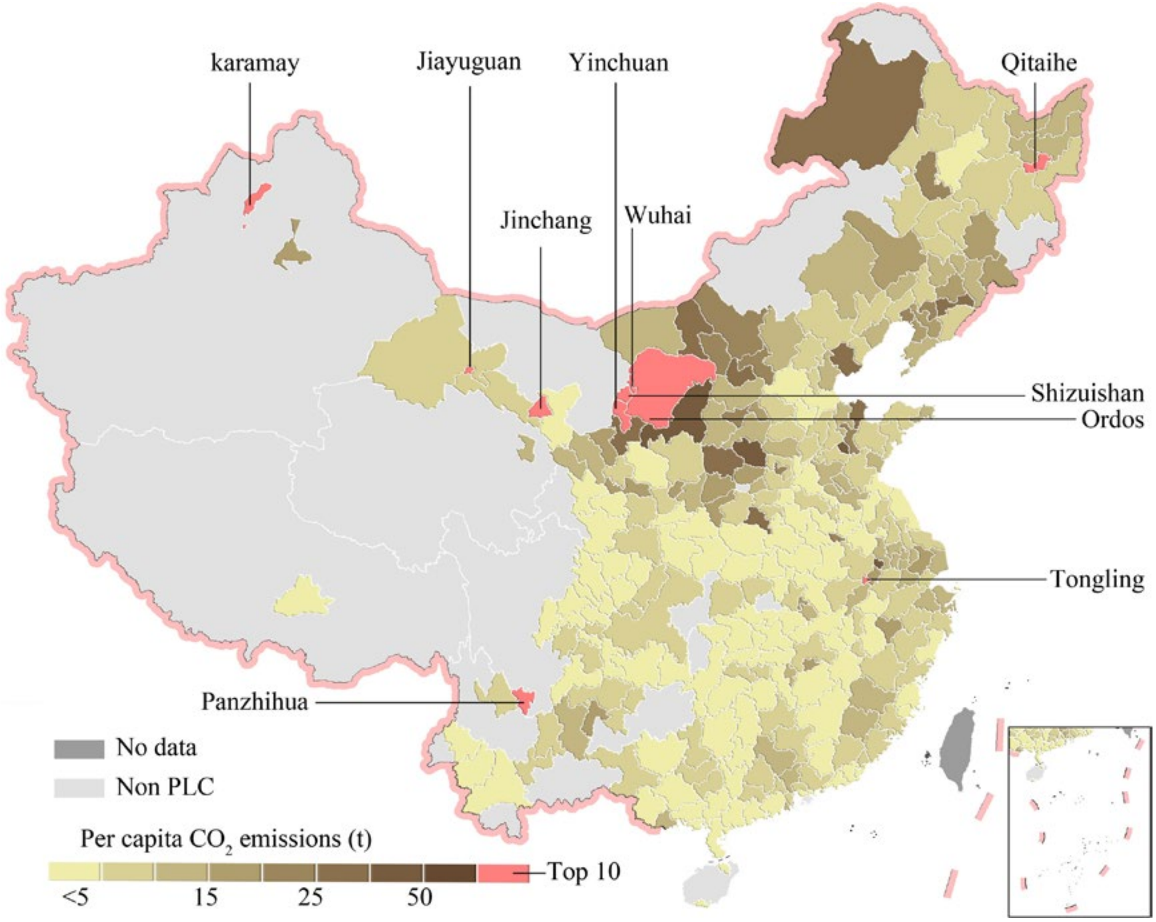

Figure 6. Distribution of the city per capita CO_2 emissions, and the top ten CO_2 emitting cities in China

Figure 7 distinguishes cities by their geographical location, i.e., eastern, central, western and northeastern China. We find that cities in western China (blue dots) have low levels of economic development, whereas the CO_2 emissions in some western cities are high compared to the national mean level. Cities in the center and northeast areas have intermediate levels of economic development and CO_2 emissions. Although cities in the east of China (red dots) have advanced economic development relative to the national mean level, they also include cities with the lowest CO_2 emissions. The pattern of fitted lines is in line with the previous graphical patterns. In China, most eastern cities are developed cities, and the service industry is much important there. Therefore, these two driving forces may explain the low carbon development in eastern cities.

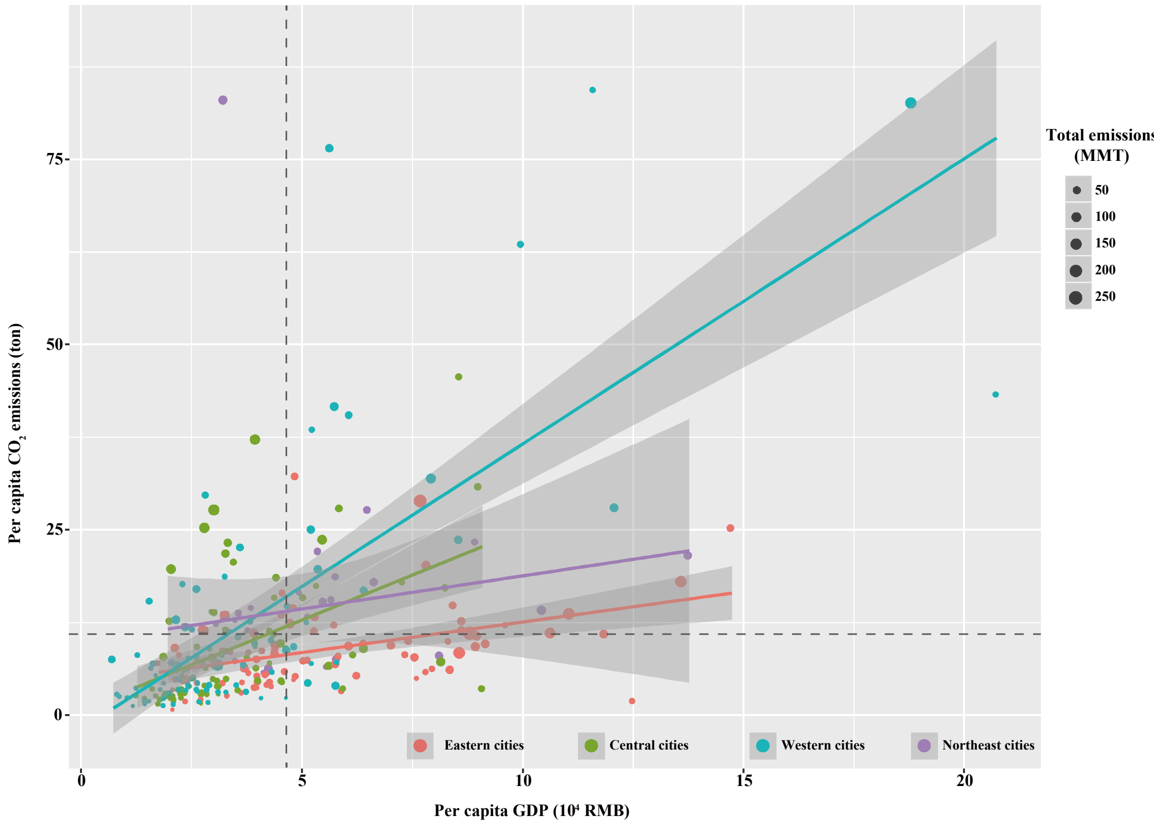

Figure 7. Correlation of CO_2 emissions and economic growth (by geographical location)

Note: Dots refer to cities, and grey areas refer to the 95% significance level. The dashed lines indicate the national mean level.

To further understand the development status of cities, 288 cities were grouped into three classes (developed cities, developing cities and less-developed cities) based on their development level according to China Business Weekly and reports of the National Bureau of Statistics on surveys of city housing prices.

Figure 8 distinguishes cities according to their development stage, i.e., developed cities, developing cities and less-developed cities. As one can observe, less-developed cities (blue dots) in the low development stage are found in two cases of high CO_2 emissions. While most less-developed cities have a low level of CO_2 emissions, some have the highest levels of CO_2 emissions. However, most developed cities (red dots) have low levels of CO_2 emissions compared to the national mean level. The slopes of the fitted lines decrease as the level of development increases, i.e., developed cities have the flattest fitted line and greatest potential for low-carbon economic development, which is partially explained by the outsourcing of heavy industries to the less-developed neighboring regions.

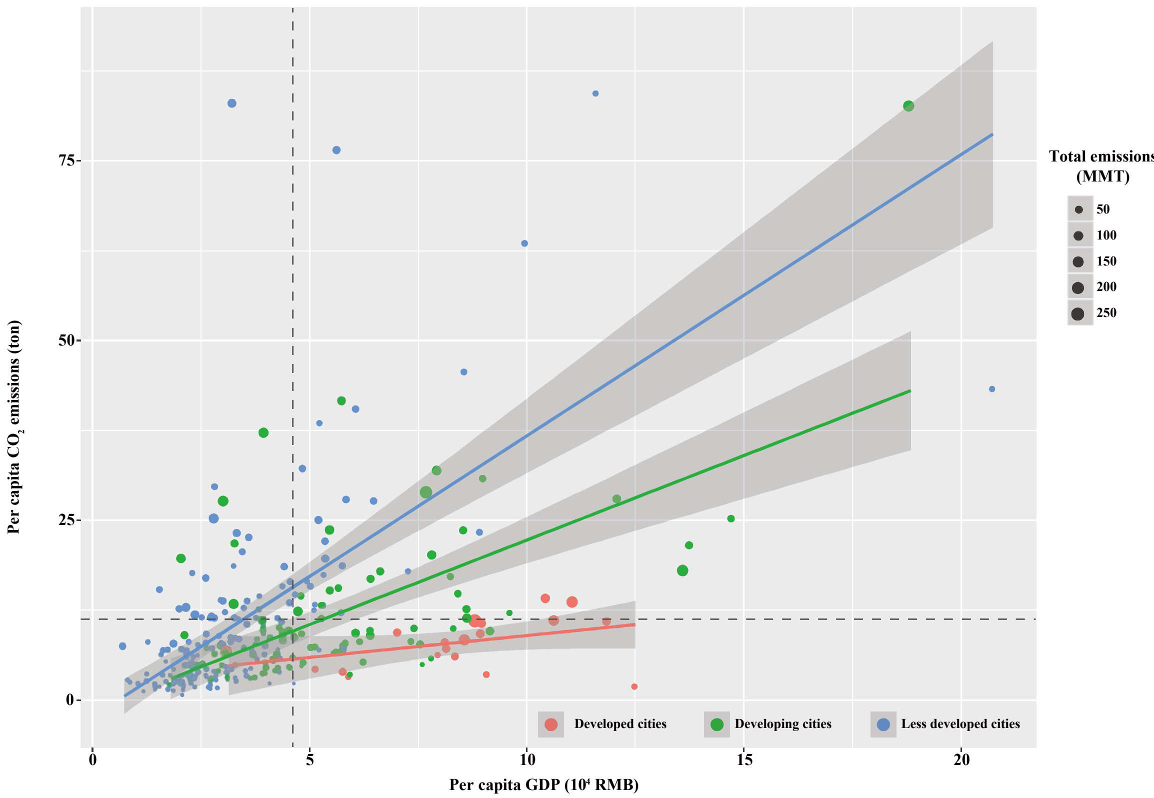

Figure 8. Correlation of CO_2 emissions and economic growth (by the city's development stage; 288 cities were grouped into three classes (developed cities, developing cities and less-developed cities) based on their development level according to China Business Weekly and reports of the National Bureau of Statistics on surveys of city housing prices.)

Note: Dots refer to cities, and grey areas refer to the 95% significance level. The dashed lines indicate the national mean level.

4. Discussion and Policy Suggestions

Urbanization is considered to be one of the main drivers accelerating economic growth and related CO_2 emissions in China. The processes of industrialization and urbanization will continue for decades and will continue to be a great challenge for Chinese cities to respond to climate change. From our observations, we suggest that city-level CO_2 emissions inventory data in China should be strengthened, especially for prefecture level cities. The inadequate energy census capacities of cities have hindered the development of an inventory system of city-level CO_2 emissions that covers all prefecture-level cities, which constrains the low carbon development of cities. The availability and quality of city-level CO_2 emissions data directly influences scientific research on city carbon emissions, formulation of low carbon strategies, and public monitoring and participation in low-carbon development at the city level. It is imperative to establish a comprehensive energy statistical system at the level of prefecture cities. Therefore, an inventory database of city CO_2/greenhouse gas emissions should be established. Standardization of the determination of city-level carbon emissions and public access to data could also be accelerated. However, within the context of the current inadequate energy data, it is feasible to establish an inventory of city-level CO_2 emissions based on CHRED to support research on city-level carbon emissions and to aid local government decision-making for low-carbon development.

Furthermore, an individual city's responsibility for emissions reduction and the portion of the national goal for emissions reduction should be established using a bottom-up approach based on specific CO_2 emission levels and the potential for emission reductions within each city. China submitted the Intended Nationally Determined Contribution (INDC) document to the secretariat of the United Nations Framework Convention on Climate Change in June 2015. In this document, China established a goal of reaching peak CO_2 emissions by 2030 or earlier and a 60% to 65% reduction of CO_2 emissions/per GDP from the 2005 levels. The national carbon emissions goal will be assigned to provinces and, eventually, to prefecture-level cities. Prefecture-level cities will become important units for achieving the carbon emission control goals. However, carbon emission reduction involves many components, such as fairness, justice, rationality, and efficiency. China is in a period of rapid economic development, and regions are developing at different rates. There are large differences among cities in terms of the total amount and intensity of emissions. A simple top-down assignment approach (national goal →provincial goal →city goal) may cause inequality among regions and cities and hinder the achievement of the maximum efficiency of emission reduction. Focusing on regions or cities with more emissions reduction potential and lower costs would be more productive. Therefore, we recommend that the emissions reduction potential for each city should be measured via analysis and comparison. This process should consider city emission inventories and social and economic development levels. City emission goals should be determined using a comparative analysis among cities. The province goals should be determined based on the affiliated city goals. Furthermore, the province goals should be compared with the national goal, and any identified gaps can be reconciled with the cities. The national goal will ultimately be achieved using a bottom-up approach (city goal→ provincial goal →national goal) through multiple analyses and optimizations. This approach will result in reasonable and fair assignment of cities' responsibilities for emissions reduction.

Finally, comparative and benchmarking research on city CO_2 emissions should be conducted, and a Top Runner system of city CO_2 emissions reduction should be established. A Top Runner system is a set of carbon emission efficiency standards that takes into account the lowest per capita emission or lowest emission per GDP in cities. Carbon emission efficiency targets are set to be achieved within a given number of years on the basis of the most efficient model on the market (the 'Top Runner'). Due to the lack of a city-level CO_2 emissions inventory system, it is difficult for cities to determine their specific and attainable low-carbon development goals through valid comparison and consultation. It is also difficult for cities to establish their own positions among other cities in China as well as in their city category (such as categories based on similar industrial structures, populations, or economic development). Cities need to set targets based on national or provincial targets or by using international cities as references. We recommend that horizontal comparisons and evaluations of CO_2 emissions be made among different categories of cities using the city CO_2 emissions inventories based on CHRED. We also recommend establishing a city-level Top Runner system for CO_2 emissions reduction. The system will promote comparison and competition between cities for the determination of low-carbon development goals as well as in the application of low-carbon development strategies. Superior organizations, such as the local and central governments, should implement policies that provide awards to the Top Runner cities that achieve the largest reduction and to motivate information sharing. In the meantime, we recommended enhancing local government and public concerns about city-level CO_2 emissions. We also encourage public involvement in the monitoring and management of city-level CO_2 emissions and the enhancement of low-carbon development.

5. Methodology

5.1 Emissions categories and inventory scopes

Anthropogenic CO_2 emissions mainly come from six major sources: fossil fuel combustion, industrial processes, waste treatment, land use change and deforestation. This study calculates CO_2 emissions from fossil fuel combustion and cement production, which is consistent with the methods used by international agencies for establishing carbon emission inventories.

Cross-boundary exchange of energy supplies, goods and materials make regional emissions inventories variable across different system boundaries. On the basis of the academic literature and previous studies, we establish two types of scopes for emission inventories. Scope 1 emissions include direct carbon emissions within the territorial boundary caused by the direct use of primary energy through industrial activity. Scope 2 emissions include emissions from purchased electricity, where the emissions are generated by upstream power plants outside of the territorial boundary.

5.2 Scope 1 emissions calculation

Scope 1 emissions calculations are widely used for national emission inventories. The IPCC guidelines for greenhouse gas emission inventories proposed two tiers of methodology for calculating scope 1 emissions, the "top-down" reference approach and the "bottom-up" sectoral approach. The main difference between these two tiers is the collection of energy consumption as activity data, in which the reference approach uses the total energy consumption data, which includes estimated energy production, stock, imports and exports. The sectoral approach uses the energy consumption of individual sectors. For the sectoral approach, sectoral level emission factors should also be used.

While the reference approach is widely used for national inventories given its significantly lower data requirement, the sectoral approach is considered to be a more precise methodology, especially since regional energy statistics often neglect energy imports/exports, which could result in their double accounting in emission estimates. Thus, the bottom-up sectoral inventory should be a priority for regional emission inventories.

Reference Approach:

$$\text{Emission} = Activity\ data_i \times Emission\ factor_i \tag{1}$$

where *i* represents the fuel type. The *Emission factor* can be further disaggregated into the net heating value of a certain fuel "*V*", carbon content "*F*" and oxidization rate "*O*". Thus,

$$\text{Emission} = Activity\ data_i \times V_i \times F_i \times O_i \tag{2}$$

Activity data in the reference approach are calculated by the national or regional energy balance:

$$Activity\ data = Energy\ production + Energy\ imports - Energy\ exports - Energy\ stocks \tag{3}$$

Bottom up Sectoral Approach:

$$\text{Emission} = \sum\sum\sum(Activity\ data_{i,j,k} \times Emission\ factor_{i,j,k} \tag{4}$$

Notes: i: fuel types, j: sectors, k: technology type.

The emission factor can be further disaggregated into the net heating value of a certain fuel "*V*", carbon content "*F*" and oxidization rate "*O*".

$$\text{Emission} = \sum\sum\sum(Activity\ data_{i,j,k} \times V_{i,j,k} \times F_{i,j,k} \times O_{i,j,k} \tag{5}$$

5.3 **Scope 2 emissions calculation**

Scope 2 emissions include emissions from power generation of purchased electricity; the emission factor for purchased electricity needs to be calculated by considered the corresponding direct emissions of power generation. For China's power supply system, electricity is supplied by regional grids; currently six grids cover the 30 mainland provinces. Thus, the emission factors of electricity supplied by each grid can be calculated as:

$$\mathrm{EFe} = \sum Emission_l \div \sum E_l \quad (6)$$

where $Emission_l$ represents the emissions of electricity for l gird. $Emission_l$ can be calculated by the aggregate of the emissions from provinces that the l state grid serves. E_l is the total electricity supply for l state grid, which contains the electricity from power plants, renewable energy and other sources.

Electricity generation data from fossil fuel power plants in each city were obtained from CHRED. Data for electricity generation from non-fossil fuel power plants in each city were from the 2012 Power Industry Statistics (China Electricity Council, 2016). Total electricity consumption data for each city were obtained from the China city statistical Yearbook (Department of Urban Socioeconomic Investigation, 2014).

6. Carbon emissions data from 288 Chinese cities

Dataset of the CO2 emissions of cities in China

Province	City	Emissions (MMT)		
		Direct	Indirect	Total
Beijing	**Beijing**	116.58	52.32	168.90
Tianjin	**Tianjin**	165.85	14.00	179.85
Hebei	**Shijiazhuang**	97.17	0.00	97.17
Hebei	**Tangshan**	183.03	37.71	220.74
Hebei	**Qinhuangdao**	24.44	1.36	25.80
Hebei	**Handan**	121.09	3.75	124.83
Hebei	**Xingtai**	51.34	14.30	65.64
Hebei	**Baoding**	43.09	12.43	55.52
Hebei	**Zhangjiakou**	50.29	0.00	50.29
Hebei	**Chengde**	26.88	3.10	29.97
Hebei	**Cangzhou**	21.49	5.52	27.01
Hebei	**Langfang**	26.92	11.32	38.24
Hebei	**Hengshui**	14.62	5.35	19.97
Shanxi	**Taiyuan**	97.77	2.29	100.06
Shanxi	**Datong**	61.82	0.00	61.82
Shanxi	**Yangquan**	21.97	0.00	21.97
Shanxi	**Changzhi**	124.49	0.00	124.49
Shanxi	**Jincheng**	42.74	0.00	42.74
Shanxi	**Shuozhou**	48.12	0.00	48.12
Shanxi	**Jinzhong**	45.25	0.00	45.25
Shanxi	**Yuncheng**	86.56	15.65	102.22
Shanxi	**Xinzhou**	39.63	0.00	39.63
Shanxi	**Linfen**	108.34	1.05	109.39
Shanxi	**Lvliang**	39.05	4.23	43.28
Inner Mongolia	**Hohhot**	68.24	0.00	68.24
Inner Mongolia	**Baotou**	74.40	0.00	74.40
Inner Mongolia	**Wuhai**	33.86	0.00	33.86
Inner Mongolia	**Chifeng**	38.28	8.50	46.78
Inner Mongolia	**Tongliao**	56.60	5.71	62.31
Inner Mongolia	**Ordos**	160.72	0.00	160.72
Inner Mongolia	**Hulunbeier**	64.09	0.00	64.09
Inner Mongolia	**Bayannur**	24.73	0.00	24.73

Province	City	Emissions (MMT)		
		Direct	Indirect	Total
Inner Mongolia	**Wulanchabu**	48.94	0.00	48.94
Liaoning	**Shenyang**	56.60	9.84	66.44
Liaoning	**Dalian**	89.51	6.28	95.80
Liaoning	**Anshan**	51.71	14.27	65.98
Liaoning	**Fushun**	38.70	1.44	40.15
Liaoning	**Benxi**	40.14	7.43	47.58
Liaoning	**Dandong**	14.31	0.00	14.31
Liaoning	**Jinzhou**	21.52	2.47	23.99
Liaoning	**Yingkou**	35.05	3.10	38.15
Liaoning	**Fuxin**	22.46	0.00	22.46
Liaoning	**Liaoyang**	34.01	7.27	41.28
Liaoning	**Panjin**	28.05	4.60	32.65
Liaoning	**Tieling**	37.77	0.00	37.77
Liaoning	**Chaoyang**	17.00	3.49	20.48
Liaoning	**Huludao**	30.34	0.00	30.34
Jilin	**Changchun**	58.89	0.00	58.89
Jilin	**Jilin**	65.74	2.36	68.09
Jilin	**Siping**	28.40	1.15	29.55
Jilin	**Liaoyuan**	15.79	0.00	15.79
Jilin	**Tonghua**	26.70	0.00	26.70
Jilin	**Baishan**	21.64	0.00	21.64
Jilin	**Songyuan**	16.32	2.71	19.03
Jilin	**Baicheng**	13.53	0.00	13.53
Heilongjiang	**Harbin**	68.47	0.27	68.74
Heilongjiang	**Qiqihar**	37.43	0.00	37.43
Heilongjiang	**Jixi**	13.58	0.00	13.58
Heilongjiang	**Hegang**	12.05	0.00	12.05
Heilongjiang	**Shuangyashan**	21.30	0.00	21.30
Heilongjiang	**Daqing**	59.87	3.12	62.99
Heilongjiang	**Yichun**	6.38	1.09	7.47
Heilongjiang	**Jiamusi**	24.59	0.00	24.59
Heilongjiang	**Qitaihe**	76.52	0.00	76.52
Heilongjiang	**Mudanjiang**	20.81	0.00	20.81
Heilongjiang	**Heihe**	10.07	0.00	10.07
Heilongjiang	**Suihua**	13.24	1.14	14.39
Shanghai	**Shanghai**	218.44	38.82	257.26
Jiangsu	**Nanjing**	86.79	0.00	86.79
Jiangsu	**Wuxi**	60.81	9.95	70.76

Province	City	Emissions (MMT)		
		Direct	Indirect	Total
Jiangsu	**Xuzhou**	105.20	0.00	105.20
Jiangsu	**Changzhou**	40.17	18.70	58.87
Jiangsu	**Suzhou**	136.94	23.51	160.45
Jiangsu	**Nantong**	39.54	0.00	39.54
Jiangsu	**Lianyungang**	13.75	0.00	13.75
Jiangsu	**Huai'an**	23.44	2.30	25.74
Jiangsu	**Yancheng**	23.84	9.52	33.36
Jiangsu	**Yangzhou**	33.06	0.00	33.06
Jiangsu	**Zhenjiang**	46.61	0.00	46.61
Jiangsu	**Taizhou**	31.69	5.58	37.27
Jiangsu	**Suqian**	8.11	12.67	20.78
Zhejiang	**Hangzhou**	52.23	29.40	81.62
Zhejiang	**Ningbo**	87.72	0.00	87.72
Zhejiang	**Wenzhou**	28.52	13.62	42.14
Zhejiang	**Jiaxing**	44.22	0.00	44.22
Zhejiang	**Huzhou**	31.39	4.31	35.70
Zhejiang	**Shaoxing**	36.51	13.27	49.78
Zhejiang	**Jinhua**	30.48	9.70	40.18
Zhejiang	**Quzhou**	28.86	6.49	35.36
Zhejiang	**Zhoushan**	4.82	0.70	5.53
Zhejiang	**Taizhou**	31.95	0.00	31.95
Zhejiang	**Lishui**	6.67	5.33	12.00
Anhui	**Hefei**	49.37	3.03	52.41
Anhui	**Wuhu**	39.24	0.00	39.24
Anhui	**Bengbu**	12.95	0.00	12.95
Anhui	**Huainan**	54.49	0.00	54.49
Anhui	**Ma'anshan**	42.38	0.00	42.38
Anhui	**Huaibei**	19.05	0.00	19.05
Anhui	**Tongling**	33.10	0.00	33.10
Anhui	**Anqing**	23.43	4.34	27.77
Anhui	**Huangshan**	2.15	1.86	4.01
Anhui	**Chuzhou**	11.62	4.05	15.67
Anhui	**Fuyang**	16.61	4.32	20.92
Anhui	**Suzhou**	14.19	0.00	14.19
Anhui	**Lu'an**	15.44	4.92	20.36
Anhui	**Bozhou**	4.65	5.09	9.74
Anhui	**Chizhou**	19.39	0.30	19.68
Anhui	**Xuancheng**	19.29	1.17	20.47

Province	City	Emissions (MMT)		
		Direct	Indirect	Total
Fujian	**Fuzhou**	23.96	0.00	23.96
Fujian	**Xiamen**	15.80	6.70	22.50
Fujian	**Putian**	9.15	1.81	10.96
Fujian	**Sanming**	30.18	3.15	33.33
Fujian	**Quanzhou**	40.80	16.30	57.10
Fujian	**Zhangzhou**	26.92	0.00	26.92
Fujian	**Nanping**	11.62	4.82	16.43
Fujian	**Longyan**	33.00	1.19	34.19
Fujian	**Ningde**	16.29	0.00	16.29
Jiangxi	**Nanchang**	13.55	4.74	18.29
Jiangxi	**Jingdezhen**	14.85	0.00	14.85
Jiangxi	**Pingxiang**	16.06	2.89	18.95
Jiangxi	**Jiujiang**	21.92	1.59	23.52
Jiangxi	**Xinyu**	19.22	1.27	20.49
Jiangxi	**Yingtan**	8.06	0.00	8.06
Jiangxi	**Ganzhou**	15.12	3.48	18.60
Jiangxi	**Ji'an**	12.86	0.00	12.86
Jiangxi	**Yichun**	29.05	0.00	29.05
Jiangxi	**Fuzhou**	5.00	2.39	7.39
Jiangxi	**Shangrao**	18.29	1.68	19.98
Shandong	**Jinan**	52.83	11.94	64.76
Shandong	**Qingdao**	41.03	12.87	53.90
Shandong	**Zibo**	90.68	1.67	92.35
Shandong	**Zaozhuang**	50.91	0.00	50.91
Shandong	**Dongying**	46.65	5.13	51.78
Shandong	**Yantai**	47.80	7.38	55.18
Shandong	**Weifang**	61.22	15.93	77.15
Shandong	**Jining**	90.93	0.00	90.93
Shandong	**Tai'an**	32.87	0.00	32.87
Shandong	**Weihai**	28.20	0.00	28.20
Shandong	**Rizhao**	37.48	3.63	41.12
Shandong	**Laiwu**	42.09	0.00	42.09
Shandong	**Linyi**	61.34	16.92	78.26
Shandong	**Dezhou**	42.00	0.53	42.54
Shandong	**Liaocheng**	36.63	0.39	37.02
Shandong	**Binzhou**	43.19	0.00	43.19
Shandong	**Heze**	35.59	5.81	41.40
Henan	**Zhengzhou**	78.94	0.00	78.94

Province	City	Emissions (MMT)		
		Direct	Indirect	Total
Henan	**Kaifeng**	13.91	4.41	18.31
Henan	**Luoyang**	64.25	0.00	64.25
Henan	**Pingdingshan**	136.63	0.00	136.63
Henan	**Anyang**	33.10	7.51	40.61
Henan	**Hebi**	32.50	0.00	32.50
Henan	**Xinxiang**	33.76	3.41	37.17
Henan	**Jiaozuo**	32.84	5.95	38.79
Henan	**Puyang**	8.46	2.94	11.40
Henan	**Xuchang**	27.64	0.00	27.64
Henan	**Luohe**	9.33	0.52	9.85
Henan	**Sanmenxia**	35.74	0.00	35.74
Henan	**Nanyang**	30.55	0.85	31.39
Henan	**Shangqiu**	52.44	6.74	59.18
Henan	**Xinyang**	15.42	0.00	15.42
Henan	**Zhoukou**	9.78	4.54	14.31
Henan	**Zhumadian**	19.90	0.00	19.90
Hubei	**Wuhan**	63.44	7.73	71.17
Hubei	**Huangshi**	26.91	1.19	28.10
Hubei	**Shiyan**	9.80	0.00	9.80
Hubei	**Yichang**	33.44	0.00	33.44
Hubei	**Xiangyang**	25.31	0.00	25.31
Hubei	**Ezhou**	18.44	0.00	18.44
Hubei	**Jingmen**	22.32	0.00	22.32
Hubei	**Xiaogan**	17.18	0.22	17.40
Hubei	**Jingzhou**	12.01	1.50	13.50
Hubei	**Huanggang**	18.83	0.00	18.83
Hubei	**Xianning**	10.03	0.00	10.03
Hubei	**Suizhou**	3.04	0.81	3.85
Hunan	**Changsha**	17.32	6.61	23.93
Hunan	**Zhuzhou**	17.70	0.12	17.82
Hunan	**Xiangtan**	22.85	2.25	25.10
Hunan	**Hengyang**	16.53	4.69	21.22
Hunan	**Shaoyang**	15.15	2.19	17.34
Hunan	**Yueyang**	23.96	1.42	25.38
Hunan	**Changde**	19.83	0.00	19.83
Hunan	**Zhangjiajie**	3.62	0.00	3.62
Hunan	**Yiyang**	13.45	0.00	13.45
Hunan	**Chenzhou**	23.38	0.00	23.38

Province	City	Emissions (MMT)		
		Direct	Indirect	Total
Hunan	**Yongzhou**	9.74	2.45	12.19
Hunan	**Huaihua**	10.39	0.00	10.39
Hunan	**Loudi**	34.54	0.57	35.11
Guangdong	**Guangzhou**	123.54	19.73	143.27
Guangdong	**Shaoguan**	24.82	0.16	24.98
Guangdong	**Shenzhen**	19.15	1.48	20.63
Guangdong	**Zhuhai**	19.05	0.00	19.05
Guangdong	**Shantou**	23.61	0.00	23.61
Guangdong	**Foshan**	52.80	17.49	70.29
Guangdong	**Jiangmen**	18.58	0.00	18.58
Guangdong	**Zhanjiang**	14.98	0.00	14.98
Guangdong	**Maoming**	12.78	3.41	16.19
Guangdong	**Zhaoqing**	18.33	7.59	25.93
Guangdong	**Huizhou**	34.65	0.00	34.65
Guangdong	**Meizhou**	30.23	0.00	30.23
Guangdong	**Shanwei**	2.30	0.00	2.30
Guangdong	**Heyuan**	9.85	0.54	10.39
Guangdong	**Yangjiang**	10.92	0.00	10.92
Guangdong	**Qingyuan**	37.73	5.96	43.69
Guangdong	**Dongguan**	59.64	18.25	77.88
Guangdong	**Zhongshan**	10.91	7.51	18.42
Guangdong	**Chaozhou**	19.42	0.00	19.42
Guangdong	**Jieyang**	7.06	4.33	11.39
Guangdong	**Yunfu**	19.53	0.00	19.53
Guangxi	**Nanning**	21.57	0.00	21.57
Guangxi	**Liuzhou**	31.37	3.65	35.02
Guangxi	**Guilin**	13.60	1.99	15.59
Guangxi	**Wuzhou**	3.68	1.40	5.08
Guangxi	**Beihai**	3.25	0.44	3.69
Guangxi	**Fangchenggang**	10.95	0.00	10.95
Guangxi	**Qinzhou**	14.25	0.79	15.04
Guangxi	**Guigang**	28.88	0.00	28.88
Guangxi	**Yulin**	12.01	4.90	16.92
Guangxi	**Baise**	22.75	0.00	22.75
Guangxi	**Hezhou**	6.90	0.84	7.75
Guangxi	**Hechi**	5.72	0.00	5.72
Guangxi	**Laibin**	16.33	0.00	16.33
Guangxi	**Chongzuo**	6.70	2.03	8.74

Province	City	Emissions (MMT)		
		Direct	Indirect	Total
Hainan	**Haikou**	5.01	2.70	7.72
Hainan	**Sanya**	2.50	0.76	3.26
Chongqing	**Chongqing**	180.31	11.60	191.91
Sichuan	**Chengdu**	42.31	14.92	57.23
Sichuan	**Zigong**	5.87	2.67	8.54
Sichuan	**Panzhihua**	49.35	0.00	49.35
Sichuan	**Luzhou**	15.85	0.98	16.83
Sichuan	**Deyang**	10.01	5.11	15.12
Sichuan	**Mianyang**	18.71	0.00	18.71
Sichuan	**Guangyuan**	9.94	1.07	11.01
Sichuan	**Suining**	3.08	1.69	4.77
Sichuan	**Neijiang**	29.70	0.26	29.96
Sichuan	**Leshan**	24.85	1.65	26.50
Sichuan	**Nanchong**	6.76	2.20	8.96
Sichuan	**Meishan**	7.66	2.92	10.58
Sichuan	**Yibin**	32.64	0.00	32.64
Sichuan	**Guangan**	19.78	0.00	19.78
Sichuan	**Dazhou**	38.37	1.19	39.55
Sichuan	**Ya’an**	4.93	0.00	4.93
Sichuan	**Bazhong**	2.61	1.64	4.24
Sichuan	**Ziyang**	4.86	2.16	7.02
Guizhou	**Guiyang**	36.56	3.40	39.96
Guizhou	**Liupanshui**	50.15	0.00	50.15
Guizhou	**Zunyi**	20.99	0.00	20.99
Guizhou	**Anshun**	16.04	0.00	16.04
Guizhou	**Bijie**	50.81	0.00	50.81
Guizhou	**Tongren**	10.98	0.00	10.98
Yunnan	**Kunming**	51.13	5.02	56.15
Yunnan	**Qujing**	70.29	0.00	70.29
Yunnan	**Yuxi**	10.41	3.20	13.62
Yunnan	**Baoshan**	4.65	0.20	4.85
Yunnan	**Zhaotong**	11.68	1.06	12.73
Yunnan	**Lijiang**	6.98	0.00	6.98
Yunnan	**Pu’er**	5.02	0.20	5.21
Yunnan	**Lincang**	3.82	0.00	3.82
Tibet	**Lhasa**	1.32	0.00	1.32
Shaanxi	**Xi’an**	26.93	9.92	36.85
Shaanxi	**Tongchuan**	15.60	0.00	15.60

Province	City	Emissions (MMT)		
		Direct	Indirect	Total
Shaanxi	**Baoji**	25.65	0.00	25.65
Shaanxi	**Xianyang**	33.31	0.00	33.31
Shaanxi	**Weinan**	69.21	0.00	69.21
Shaanxi	**Yan'an**	12.11	3.90	16.00
Shaanxi	**Hanzhong**	11.24	6.08	17.32
Shaanxi	**Yulin**	107.70	0.00	107.70
Shaanxi	**Ankang**	5.47	0.64	6.11
Shaanxi	**Shangluo**	4.66	3.70	8.36
Gansu	**Lanzhou**	36.20	0.54	36.74
Gansu	**Jiayuguan**	16.85	2.72	19.57
Gansu	**Jinchang**	17.94	0.00	17.94
Gansu	**Baiyin**	19.87	0.00	19.87
Gansu	**Tianshui**	7.35	4.07	11.42
Gansu	**Wuwei**	3.89	0.31	4.21
Gansu	**Zhangye**	7.64	0.00	7.64
Gansu	**Pingliang**	31.84	0.00	31.84
Gansu	**Jiuquan**	7.71	0.00	7.71
Gansu	**Qingyang**	3.80	3.87	7.67
Gansu	**Dingxi**	3.70	4.30	8.00
Gansu	**Longnan**	4.74	2.18	6.92
Qinghai	**Xining**	22.43	5.64	28.06
Ningxia	**Yinchuan**	83.23	0.00	83.23
Ningxia	**Shizuishan**	55.64	0.00	55.64
Ningxia	**Wuzhong**	33.14	0.00	33.14
Ningxia	**Guyuan**	7.98	2.04	10.02
Ningxia	**Zhongwei**	12.95	6.26	19.21
Xinjiang	**Urumqi**	52.87	0.00	52.87
Xinjiang	**Karamay**	14.99	1.96	16.95

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