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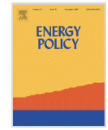

Urban energy use and carbon emissions from cities in China and policy implications

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Abstract

Urban areas contain 40% of the population and contribute 75% of the Chinese national economy. Thus, a better understanding of urban energy uses is necessary for Chinese decision-makers at various levels to address energy security, climate change mitigation, and local pollution abatement. Therefore, this paper addresses three key questions: What is the urban contribution to China's energy usage and CO_2 emissions? What is the contribution of large cities, and what alternate energy–economy pathways are they following? How have energy uses and CO_2 emissions transformed in the last two decades in key Chinese cities? This three-tier analysis illustrates the changes in urban energy uses and CO_2 emissions in China. The results show that the urban contributions make up 84% of China's commercial energy usage. The 35 largest cities in China, which contain 18% of the population, contribute 40% of China's energy uses and CO_2 emissions. In four provincial cities, the per capita energy usage and CO_2 emissions have increased several-fold. Rapid progress was made in reducing the carbon intensity of economic activities in cities throughout the 1990s, but alarmingly, such progress has either slowed down or been reversed in the last few years. These results have important policy implications.

Keywords

Urban energy uses; Urban carbon management; China

1. Introduction

China contributes 5% of the world's Gross Domestic Product (GDP), which is 14.5% in terms of Parity in Purchasing Power (WEO, 2007). Its primary energy demand in 2005 was 1742 million tons of oil equivalents (Mtoe), which was 15% of global primary energy demand. Accordingly, CO_2 emissions from energy usage in China totaled 5101 million tons in 2005, which represented 19% of worldwide emissions (WEO, 2007). The reference scenario of the International Energy Agency (IEA) projects that the primary energy demand in China will increase by a factor of 2.2, reaching 3819 Mtoe in the year 2030, and will surpass the United States after 2010. Therefore, despite having smaller per capita energy usage and CO_2 emissions, China's energy policy has a strong impact on the international energy supply and demand. Therefore, China's energy security concerns have a considerable impact on international energy markets.

In 2005, China's urbanization rate was 40%, representing 531 million urban dwellers, which is 17% of the world's urban population (UN, 2007). UN projections show that urbanization in China will grow rapidly, reaching up to 60%, or 880 million urban dwellers, in 2030. A recently released report by the McKinsey Global Institute (MGI) puts that number at one billion by 2030, with mega (over 10 million) and mid-sized (1.5–5 million) cities growing faster than others (MGI, 2008). This report also showed that by 2025, 90% of China's GDP will be generated by the urban economy and the GDP generated by cities will increase from the current 75% to 95%.

Increasing urbanization is a national policy priority in China, where urbanization has been perceived by decision-makers as a necessary element to economic and industrial growth. Accordingly, China's 11th Five Year Plan aims to increase the urbanization rate to 47% by 2010 (Raufer, 2007). However, increased urbanization demands greater energy use in a rapidly developing economy like China. This is mainly due to rising incomes and the continuous concentration of energy-consuming sectors into urban areas. Rising incomes make urban dwellers' lifestyles more energy intensive, and the new urban migrants demand greater per capita energy then their rural settlements (existing and new migrants will make up 40% of the urban population by 2025 in China[1]). There has been a long debate in academia on the advantages of higher settlement density for reducing energy uses in cities (Anderson et al., 1996; Newman and Kenworthy, 1989; Steemers, 2003; Isabelle and Lafrance, 1999; Minadali et al., 2004). This indicates that when China's urbanization rate increases from 40% to 60% from 2005 to 2030 and reaches 880 million (UN projection) or one billion (MGI estimate), urban areas will play a greater role than at present to shape China's energy demand and CO_2 emissions.

China is already aggressively engaged in securing energy resources internationally and has already passed the United States as the largest emitter of CO_2 (Global Carbon Project, 2008). Thus, energy security and climate change mitigation have emerged as key policy priorities in China due to its greater energy demand. In addition, pollution is another key concern in China's urban areas. Since coal and oil dominate the energy system, they are intricately linked to the increases in particulate emissions, acid rain, and automobile pollution such as NO_x and ozone. Sixteen Chinese cities are listed among the world's 20 most polluted cities, and this has alarmed policy-makers (Economist, 2004). Urban energy systems and the urban infrastructure at the center of the necessary countermeasures to tackle them can make positive impacts that could last for several decades (Raufer, 2007). In China, however, energy concerns have historically played a smaller role in urban planning. Two forms of planning affect urban energy in China. The first is the economic and social development planning at all governmental levels through Five Year Plans, and the second is through the actual physical development associated with the Ministry of Construction (Raufer, 2007). China's 11th Five Year Plan recognizes the importance of energy for economic growth but fails to sufficiently recognize the opportunities that exist in improving the efficiency of the urban system as a whole. Another concern in China is the blind expansion of cities, which is often promoted by the city governments themselves due to a variety of political reasons. Such interests have intensified in recent years in order to attract investments, while the central government's guidance on urban development and related coordination has been lacking (Wen, 2005). China does not have a ministry or agency in charge of coordinating the various aspects of urbanization and urban systems that are scattered among various agencies. The 11th Five Year Plan, like its predecessors, fails to provide guidance on how to keep up with the rapid urbanization in regards to the specific economic and regional conditions of cities (Wen, 2005).

In this context, the major aims of this paper are three. The first aim is to show the urban contribution to China's energy uses and thus highlight their importance in determining the energy and carbon profiles of the nation. There are no such estimations available as of now. This helps illustrate how important urban areas in China are for key ongoing national concerns such as energy security, climate change mitigation, and the target of a 20% reduction in energy intensity between 2005 and 2010, which was included in the 11th Five Year Plan. In China, since major policies are usually made at the central level and implemented by provincial and city governments, a better understanding of urban areas' roles will help to devise a much needed integrated national framework and policies for addressing urban development, energy, and climate change concerns collectively. The second aim is to show the internal dynamics of urban areas in relation to energy usage and CO_2 emissions at the meso-scale by estimating and analyzing the highly urbanized and economically most important 35 cities, as defined by China's National Plan. Our aim here is to see how these cities compare in terms of energy-economic relationships and what that means collectively to China for energy consumption and CO_2 emissions. The third aim is to illustrate the historical changes in urban energy uses and CO_2 emissions and their drivers in urban areas at the micro-scale through a detailed analysis of Beijing, Shanghai, Tianjin, and Chongqing. Although these four cities may not be a representative case, they represent the rapid urbanization, economic growth, and the accelerated changes in technology, lifestyle, and societal transformation. This three-tier analysis—at the national scale, meso-scale, and micro-scale—collectively illustrates the considerable implications for key policies such as energy efficiency and climate change mitigation in China.

2. China's urban energy consumption

In China, not all cities and towns are urban areas. Cities and towns are politico-administrative units. The designation of the title of "City" to a place has historically had political, resource distribution, and other repercussions in China. Therefore, the city and town population, and the urban population, are two different numbers in China, with the latter a subset of former. Similarly, the level of the authorities of a city in China depends on whether the city is designated as provincial, prefectural, county level, or township level. This is because the basic building blocks of China's administrative system are categorized as province, prefecture, county, township, and villagers' or citizens' committees.

The best way to estimate China's urban energy consumption would be to determine the energy consumption of each of the 661 designated cities and over 19,000 towns and then divide them into urban and rural energy uses. However, China's statistical reporting system does not publish energy use by its designated cities and towns. Similarly, the information on the contribution of urban areas' energy usage in each of the designated cities and towns is not available. Energy use information is available only for a few large cities. The greatest contribution to China's urban population comes from the smaller urban agglomerations, whose information base is poor, and the smallest contribution comes from the larger urban agglomerations, whose information base is relatively better (Fig. 1).

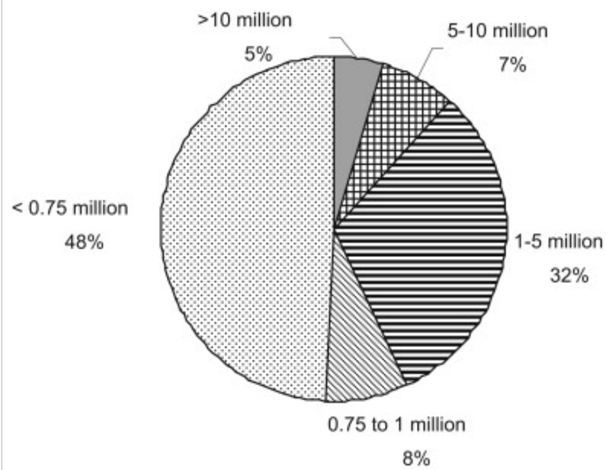

Fig. 1.

Share of urban agglomeration size in total urban population in 2005. *Source*: Estimated by author based on UN (2007).

Figure options

Therefore, an aggregated and top-down methodology is essential for estimating urban energy uses in China. This has to be done on the basis of parameters or coefficients that are relatively stable across a number of scales. Therefore, in this study, we used energy intensity of economic activities, i.e., energy consumption per unit Gross Regional Product (GRP), as a key indicator on the basis of which urban energy of China for the year 2004 is estimated. Other parameters that we used in the estimation are urban district population and GRP generated from urban districts of cities, as shown below. In the equation below, UE is urban energy consumption in the designated cities and towns:

$$\mathrm{UE}=\sum_{i=1}^{287}\mathrm{UGRP}_i\,\mathrm{EI}_i+\sum_{j=1}^{374}\mathrm{UGRP}_j\,\mathrm{EI}_j+\sum\mathrm{UE}_{\mathrm{others}}$$

Turn on

where UGRP is the GRP generated by the urban areas of the cities (urban districts), EI is the energy consumption per unit GRP of the urban districts of cities, i is the number of cities at the provincial, quasi-provincial, and prefectural levels, which are 4, 15, and 278, respectively, and *j* is the number of cities at the county level, which is 374. UGRP_i is obtained from the CCSY (2005). For the county level cities (*j* in the equation above), the publications report only the urban area population and the total city GRP but not the urban share of city GRP. Therefore, in order to determine UGRP_j, we assumed that the share of urban district GRP is the same as that of the urban area population to the city population (Table 1). Thus, we assumed that the per capita GRP of the urban area is the same as the per capita city GRP, so we might have slightly underestimated the urban GRP because the per capita GRP of urban areas can be expected to be higher than the city's average GRP. For EI_i and EI_j, the city-specific energy consumptions for all of the 661 cities were not available; therefore, we assumed the same energy intensity for cities as that of the province to which the city belongs. The provincial energy intensity in this study is calculated from the provincial energy use and GRP available from the CSY (2005), as shown in Table 2. This assumption could have slightly overestimated the urban energy consumption because we expect the energy intensity of cities to be slightly lower than the provincial average. However, this helps to cancel out some underestimation that may have occurred earlier. Given the data limitations, this is a reasonable assumption since the energy intensity is a stable indicator across various spatial scales because it internalizes the income effect, on which the energy consumption largely depends.

Table 1.

Urban population and urban GRP of cities for the year 2004.

	Urban district population (million)	Urban district GRP (billion Yuan)
Cities at province and prefecture level (287 in number)	350.8 (37% of city population)	9170 (56% of city GRP)
Cities at county level (374 in number)	62.8 (26% of city population)	950 (28% of city GRP)

Source: Calculated by author based on CCSY (2005).

Average exchange rate for Yuan in 2004 was 8.277 Yuan/US$.

Table options

Table 2.
Energy intensity of provinces in China for 2004.

Province	Energy intensity, SCE/10,000 Yuan
Beijing	1.20
Tianjin	1.26
Hebei	1.79
Shanxi	3.69
Inner Mongolia	2.81
Liaoning	1.90
Jilin	1.89
Heilongjiang	1.40
Shanghai	0.99
Jiangsu	0.88
Zhejiang	0.96
Anhui	1.25
Fujian	0.76
Jiangxi	1.09
Shandong	1.26
Henan	1.48
Hubei	1.44
Hunan	1.27
Guangdong	0.94
Guangxi	1.26
Hainan	0.96
Chongqing	1.34
Sichuan	1.63
Guizhou	3.94
Yunnan	1.76
Shaanxi	1.65
Gansu	2.50
Qinghai	2.92
Ningxia	5.04
Xinjiang	2.23

Source: Calculated based on GRP and total energy consumption in CSY (2005).

Note: SCE is standard coal equivalent. The original units used in Chine Energy Statistical Yearbook i.e. SCE is used in order to maintain consistency and make comparisons.

Table options

The energy usage estimated by the first two parameters on the right-hand side of the above equation alone does not give the complete picture since the equation represents only 76% of the total urban population of the country. They do not consider the energy consumed by the urban population outside the urban districts of the 661 cities and over 19,000 towns. Therefore, the energy used by the remaining 24% of the urban population that is largely outside of the urban districts of cities and towns needs to be accounted for. These urban areas are mainly smaller settlements that have characteristics similar to the urban areas of the county level cities. Therefore, to estimate the energy consumption of the remaining 24% of the urban population (UE_{others}), the average per capita urban energy usage for county-level cities are assumed.

The total energy consumption, as defined in China's energy statistical system, is the sum of the total final energy demand, the losses due to energy distribution, and the conversion losses for energy transformation such as electricity and heat production. Thus, energy consumption (unless otherwise stated) means the primary energy demand. For electricity and heat production, although the actual energy consumption and carbon emissions may take place outside of urban areas, they are accounted for in urban energy estimates. Similarly, this analysis is based on the reported data by China's statistical yearbooks, which show only the commercial energy (including hydro electricity, coal, oil, gas, their products, and electricity) but ignore production of fuel of low calorific value, bio-energy, and other non-commercial energy (CESY, 2005a and CESY, 2005b). Caution should be used when we compare this with other energy statistical systems such as the International Energy Agency, which also includes non-commercial energy uses.

The results of the estimations (Table 3) show important insights into the urban contribution. First, the urban contribution to China's total commercial energy uses is found to be enormous −84% in 2006. Secondly, the gap between the urban and rural populations for commercial energy uses is massive; the ratio between the urban and rural per capita commercial energy usage is 6.8, and that between the urban and national usage is 1.9. If we consider fuels with lower calorific values such as bio-mass and other forms of renewable energy, the urban contribution is expected to be slightly lower due to the accounting of large bio-mass uses in the rural areas. However, information on non-commercial energy is not available in China's published energy statistical data books. IEA statistics show that bio-mass and other renewable contributed 10.6% of the total energy uses in China in the year 2006 (WEO, 2007). If we take these IEA numbers for non-commercial energy uses and further assume that the urban areas use only the commercial forms of energy, then the urban contribution to the total energy consumption of China would be 75% in 2006, as shown in Table 4.

Table 3.

Estimated China's urban energy consumption.

	2004	2006	
Total urban energy consumption	1,638	2071	Million tons of SCE
Per capita urban energy consumption	3.02	3.59	Tons of SCE/person
Per capita rural energy consumption	0.52	0.53	Tons of SCE/person
Per capita total energy consumption	1.56	1.87	Tons of SCE/person
Urban to national per capita energy ratio	1.93	1.92	
Urban energy's share in total	80.58%	84.07%	Based on national energy as 2032 and 2463 million tons of SCE, respectively

Note: 1. Total energy consumption includes total final energy demand, distribution losses and conversion losses. Only commercial energy consumptions are considered. Therefore, this should be interpreted as urban's share in total commercial primary energy demand.

2. Scaling from 2004 to 2006 is done by the following simple method: Urban energy in 2006=urban energy in 2004×(Urban pop 2006/Urban pop 2004)×(Natl. Energy 2006/Natl. Energy 2004)

3. The urban population figures reported in China's official statistical books differ slightly from UN estimates. In order to maintain consistency, data from China are used.

Table options

Table 4.

Derivation of urban energy consumption of China by scaling to IEA's China energy statistics for the year 2006.

	Total energy	Commercial energy		Biomass, waste and other renewable	
	Mtoe	Mtoe	% total	Mtoe	% of total
China, IEA 2006					
Total final consumption	1215	988	81.32	227	18.68

Losses and transformation	967	962	99.55	4	0.45
Total primary energy demand	2182	1951	89.40	231	10.60
Estimated urban contribution, 2006					
Total final consumption	831	831	100	0	0
Losses and transformation	809	809	100	0	0
Total primary energy demand	1640	1640	100	0	0
Urban contribution in primary energy demand	75.15%	84.07%		0	0

Table options

There is no direct way to verify this estimate due to the lack of other such estimates, either for China or for other countries. One indirect way to check the consistency of this estimate is to use a deductive approach to the national energy statistics for China, in which energy use components that do not belong to urban areas are deducted and compared. In order to do this check of consistency, we selected two different national energy statistics; the first is from IEA, and the second is from the China Energy Statistical Yearbook. The results shown in Table 5 illustrate that our estimation is realistic.

Table 5.

Triangulation of results for final energy consumption (TFC).

Item	Our urban energy estimation	IEA (WEO, 2007)	China Energy Statistical Yearbook (2005)
Deducted items from national energy statistics →		• Agriculture sector • Biomass and other renewable	• Agriculture sector • Rural residential sector
Urban TFC, 2006	831 Mtoe	827 Mtoe	
Urban TFC, 2004	1637 mn SCE[a]		1781 mn SCE

a Urban TFC's share in urban energy consumption is assumed same as that for nation's total energy, 95.51% (CESY, 2005a and CESY, 2005b).

Table options

3. Energy uses in China's key cities

In Section 2, we saw that the urban contribution to energy uses is enormous, despite the low urbanization rate (41%). In this section, we analyze and illustrate the internal dynamics of urban areas through the differences and commonalities of their energy usage between cities that are highly urbanized and explicitly designated in China's National Plan as important cities for economic development. For this analysis, we first estimate the contributions of these 35 cities and then show the different pathways that they exhibit. Such a comparison, even though it is derived from a modest methodology, is the first published comparison. Secondly, we carry out a detailed historical analysis of energy uses and carbon emissions from four highly urbanized and trendsetting cities, namely, Beijing, Shanghai, Tianjin, and Chongqing, in order to explain the urban energy and CO_2 transitions.

3.1. China's key 35 cities

The National Plan of China has designated 35 cities as key cities that represent provincial capitals, provincial cities, and other economically important cities.[2] They are the most important cities in China for economic growth and infrastructure development. They are often viewed as cities that set trends for popular life style and consumption patterns, as well as for new technology and policies. Therefore, these cities also take the lead in the implementation of key policy measures in urban energy efficiency and climate change mitigation.

In order to estimate the total energy consumption from these cities, we used the average carbon and energy intensity (energy/carbon per unit GRP) of the province to which the city belongs as a proxy for the city's energy and carbon intensity. Since energy intensity is a relatively robust indicator across multiple scales (because of the strong links between economic activities and energy uses), this is a reasonable assumption when energy data for each city are not available. We obtained each city's GRP from CSY (2007). We calculated the energy uses and CO_2 emissions of each province of China from the original energy balance tables expressed in the physical units from the China Energy Statistical Yearbook 2007 and used the appropriate calorific value and emission factor for each fuel type, as shown in Table 6.

Table 6.

Calorific value and emission factors of fuel types.

	Calorific value	Carbon emission factor (not CO_2) (t-C/TJ)
Raw coal	20,934 KJ/Kg	26.8
Cleaned coal	26,377 KJ/Kg	26.8
Other washed coal	8374 KJ/Kg	26.8
Briquettes	20,934 KJ/Kg	26.8
Coke	28,470 KJ/Kg	29.5
Coke oven gas	17,375 KJ/cu m	13.0
Other gas	5234 KJ/cu m	13.0
Other coking products	28,470 KJ/Kg	29.5
Crude oil	41,868 KJ/Kg	20.0
Gasoline	43,124 KJ/Kg	18.9
Kerosene	43,124 KJ/Kg	19.6
Diesel oil	42,705 KJ/Kg	20.2
Fuel oil	41,868 KJ/Kg	21.1
LPG	50,241 KJ/Kg	17.2
Refinery gas	46,055 KJ/Kg	18.2
Other petroleum products	41,868 KJ/Kg	25.8
Natural gas	38,979 KJ/cu m	15.5

Table options

The analysis, shown in Table 7, shows that these cities represent less than one-fifth of the population but produce a large share of the nation's GDP. Collectively, they consume 40% of the total commercial energy of the nation and emit CO_2 at similar levels. The wide disparity between these cities and the nation in per capita GDP, per capita energy consumption, and per capita CO_2 emissions shows that their influence to shape the national energy and carbon profile is disproportionate compared with their population.

Table 7.

Key indicators and estimated energy and CO_2 of key 35 cities of China, 2006.

	China	35 cities	35 cities' contribution
Total population, million	1314	237	18%
GRP (market price), billion US$	2719	1109	41%
Total commercial energy consumption, mn TJ	65.7	26.2	40%
Per capita commercial energy consumption, MJ/person (registered permanent population)	50,000	110,771	2.2 times more
Per capita GDP/GRP, US$/person (registered permanent population)	2068	4681	2.3 times more
CO_2 emissions (Commercial energy-related), mn tons	5645	2259	40%
Per capita CO_2 emissions (Commercial energy-related), tons/person	4.30	9.54	2.2 times more

Sources: Calculated from base data of CSY (2007) and CESY (2007) by author. The energy and carbon emissions of 35 cities are based on city's GRP and average energy and carbon intensity of each province to which each city belongs. Author calculated provincial carbon emission for 35 provinces from energy balance tables from CESY (2007) using parameters shown in Table 6. The CO_2 and energy figures for China are slightly different from other estimates such as IEA due to different accounting system and calorific value of fuels.

Table options

Apart from the differences between these cities and the nation, there are large differences within these cities, as demonstrated in Fig. 2. Among these cities, Shenzhen stands out with extraordinarily high per capita GRP (38,000 US$/person). Shenzhen is a gateway to China from Hong Kong and is a center for financial markets and other manufacturing establishments. Fig. 2 shows three clear pathways of China's 35 key cities. The first is the low-energy consumption and high economic output path adopted by cities like Fuzhou, Nanjing, Ningbo, Beijing, Guangzhou, Shanghai, and Xiamen; the second is the high-energy consumption and low economic output path adopted by cities like Xining, Yinchuan, Guiyang, Urumqi, Taiyuan, Hohhot, and others; and the third is in between these two. The first group of cities is largely situated in central and western China with energy-intensive industries and cooler climates, while the second group of cities is largely in the eastern part of the country, close to the coast with relatively a warmer climate, and has a strong presence of service industries.

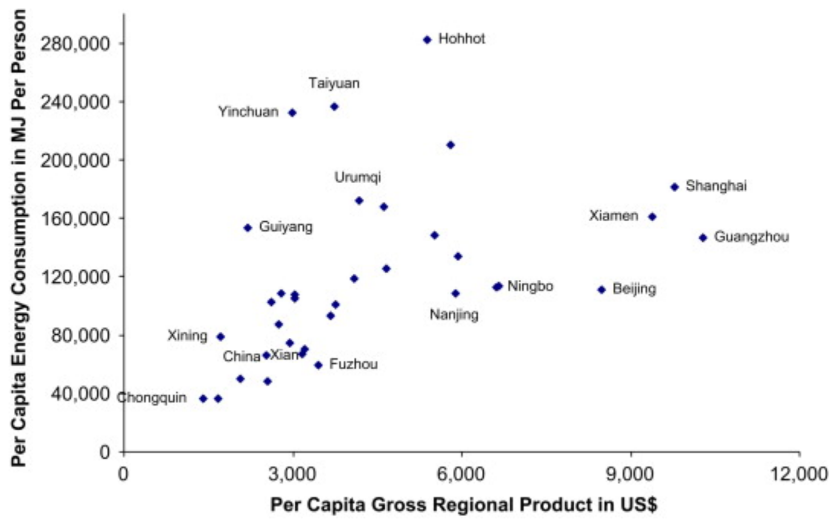

Fig. 2.

Per capita income and per capita energy consumption in 34 largest Chinese cities in 2006. *Note*: Shenzhen is removed from this figure because scale of the axes is too small. Per capita income and energy of Shenzhen are high for the graph's. *Source*: Estimated by Author based on CSY (2007) and CESY (2007).

Figure options

3.2. Energy use and CO_2 emission changes in four provincial cities—Beijing, Shanghai, Tianjin, and Chongqing

The historical changes in urban energy use and CO_2 emissions that are taking place in a few key cities, such as Beijing, Shanghai, Tianjin, and Chongqing, help illustrate the speed and size of the urban energy and CO_2 changes taking place in Chinese cities. These cities are the four most prominent mega-cities whose populations exceed ten million, and they have provincial status in China's political and administrative system. Beijing, Shanghai, and Tianjin have been provincial cities for many decades and are highly urbanized; Chongqing was a part of Sichuan province until early 1997 and is now the largest municipal government in China, with a registered population of close to 30 million. Table 8 outlines the basic indicators of these cities.

Table 8.

Basic indicators of Beijing, Shanghai, Tianjin and Chongqing, 2006.

City	Beijing	Shanghai	Tianjin	Chongqing
Area, km^2	16,410	6340	11,920	82,400
Resident population, million	15.81	18.15	10.75	28.08
Registered population, million	11.98	13.68	9.49	31.99
Urban share in resident population, %	84	89	76	47
Gross regional product, billion US$	98.7	130.0	54.7	43.8
Total energy use, thousand TJ[a]	1332	2480	1271	1160
Total energy related CO_2 emissions, million tons[a]	142.10	228.74	117.61	103.97

Source: Statistical Yearbook of each of four cities and CSY (2007). Exchange rates are from database of International Monetary Fund.

a Author's calculation based on energy balance table of each city from CESY (2007). The Calorific values and emission factors used in calculation are shown in Table 6.

Table options

We estimated historical energy uses and CO_2 emissions from these cities using the energy balance tables from 1985 onwards. For Beijing, Shanghai, and Tianjin, energy data are available in the China Energy Statistical Yearbooks. In the case of Chongqing, energy data are available only from 1997, which is after Chongqing city came into existence. For the early years, energy statistics are available at 5-year intervals from 1985 to 1995 and then for each year until 2006 (CESY, 1986, CESY, 1998, CESY, 2001, CESY, 2004, CESY, 2005a, CESY, 2005b, CESY, 2006 and CESY, 2007). Since the energy data were in physical units, the calorific values and emission factors that were used for calculating the energy and CO_2 emissions for each fuel type are shown in Table 6. For electricity, three separate emission factors for each year are used, i.e., for indigenous electricity production, thermal plants, and imported heat and electricity. For the first two, emission factors are derived from energy balance tables using the actual fuels burned, their estimated carbon emissions, and the amount of electricity and heat produced. For imported electricity, we assumed that the emission factors are the same as the average emission factor of national electricity production.

3.2.1. Sectoral and fuel transitions

Fig. 3 shows the historical energy uses, CO_2 emissions, and the economy in the cities. It shows a rapid growth in energy uses and CO_2 emissions from cities, which is seen to have accelerated from the early 2000s. In Shanghai, our analyses show that emissions have increased by five times from 1985 to 2006, in contrast to 2.6 times for Beijing in the same period. Even in the period 1997–2006, for which a comparison was possible for all four cities (Chongqing came to existence in 1997), Shanghai doubled its emissions compared with about 1.7 times in the case of the other cities. Until 1990, the emissions difference between Beijing and Shanghai was nominal, but it started to widen after China's economic growth accelerated. By 2006, the gap in emissions amongst the four cities was large. In 1995, the per capita CO_2 emissions of Beijing, Tianjin, and Shanghai were all close to 8 tons; however, by 2006, these emissions had doubled in Shanghai but had only increased by half in Beijing and Tianjin. Chongqing has trailed behind the others. The speed with which Shanghai increased its GRP largely explains the growth in energy use and CO_2 emissions. Fig. 3 also shows that the per capita CO_2 emissions of Shanghai are the highest and have grown by several times from 1985 to 2006. However, caution should be taken in assessing Beijing and Shanghai's per capita estimations for recent years based on the registered population because the floating population in both Shanghai and Beijing accounted for nearly 32% of the registered population in 2006. In both cities, the floating population was only about 2% in 1985. The floating population accounted for 13% of the registered population in Tianjin in 2006. Chongqing is in the opposite situation compared with the other three cities: the resident population is 12% less than the registered population because of migration out of the region. If we account for the floating population, the per capita CO_2 emissions of Beijing and Shanghai would be 9 and 12.6 tons, respectively—much less than shown in Fig. 3.

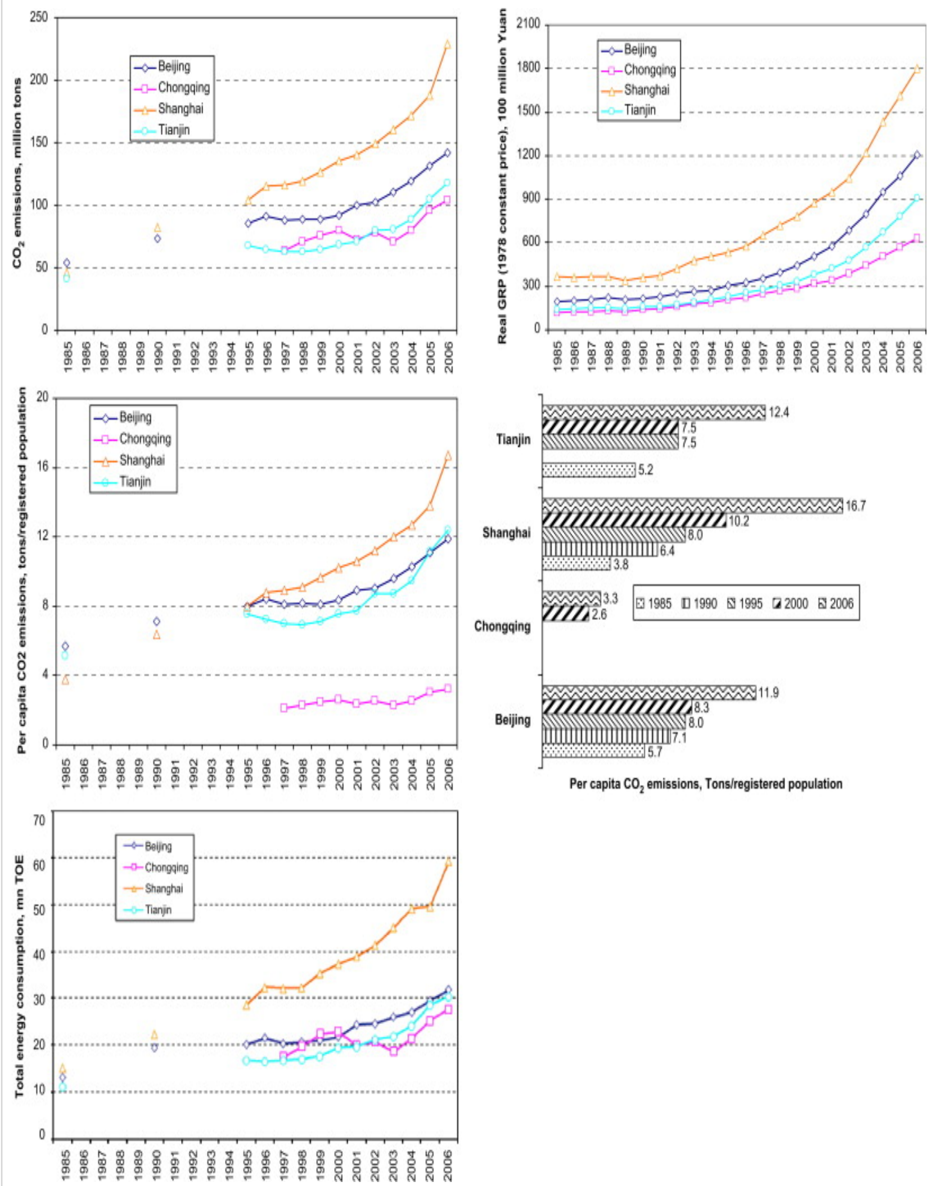

Fig. 3.

CO_2 emissions, per capita CO_2 emissions, and Gross Regional Product of cities, 1985–2006.

Figure options

Our sectoral analysis shows that the industrial sector has historically dominated CO_2 emissions in these cities (Fig. 4). In particular, Beijing and Shanghai have gone through rapid transformations in the period 1985–2006, characterized by the rapidly declining share of the industrial sector in total CO_2 emissions (65–43% for Beijing and 75–64% for Shanghai) and the rising share of the commercial and transportation sectors. This transformation has been faster in Beijing than in Shanghai. However, the transformation has been slower in Chongqing and the slowest in Tianjin. In Tianjin, the share of the industrial sector of total CO_2 emissions has increased slightly from 63% in 1985 to 70% in 2006. The share of the residential sector has remained more or less unchanged over the last two decades for Beijing, Shanghai, and Tianjin and for the last decade for Chongqing. In the case of the transportation sector, the shares in 2006 are relatively smaller (between 7% for Tianjin to 16% for Beijing), but their growth rates have been very high due to the rising car ownership rates in these cities (Table 4). Despite having strong control over vehicle ownership in Shanghai, the CO_2 emissions from the transportation sector have increased by eight times in the period 1985–2006. Beijing registered close to a sevenfold increase in the same period. In the last decade alone, CO_2 emissions have increased by a factor of almost 3.5 in Tianjin and Chongqing.

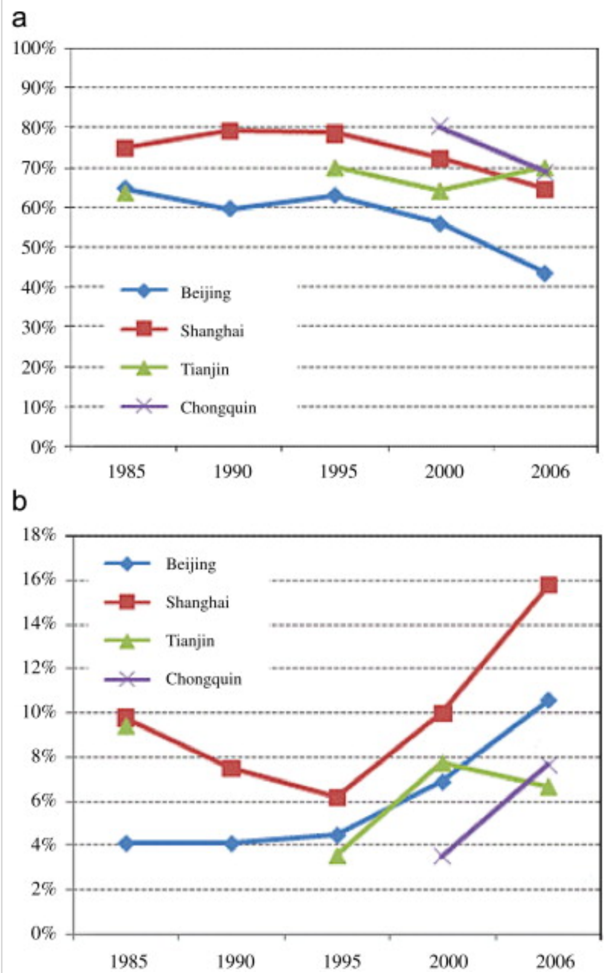

Fig. 4.

Share of sectors in energy-related CO_2 emissions in cities. (a) Industrial sector, (b) transport sector.

Figure options

With respect to fuel usage, a rapid change in CO_2 emissions is taking place as well. First, a rapidly declining trend of the share of direct coal burning (including briquettes and coke) in CO_2 emissions and energy consumption is evident. In Beijing, Shanghai, and Tianjin, coal's share of CO_2 emissions has declined from 58% to 26%, 51% to 18%, and 61% to 33%, respectively, in the period between 1985 and 2006, thus showing a rapid transition. In Chongqing, coal contributes a much higher share of CO_2 emissions (about 46% in 2006) compared with the other cities, but it has declined considerably from 63% in 1997. Secondly, the share of electricity and oil in CO_2 emissions and energy consumption is rising, which is compensating for the declining share of coal burning. The example from Beijing shows that CO_2 emissions from electricity use increased by over 5-folds in 1985–2006, and its share doubled from 20% to 40% over the same period. Shanghai is similar to Beijing, and in the remaining two cities CO_2 growth from electricity use is relatively slower. The rise in electricity usage is more noticeable than oil in all cities except Shanghai, where both electricity and oil form the main feature of the energy system. In Shanghai, oil contributed 50% of the final energy consumption in 2006, a rate much higher than the other cities. Third, the role of natural gas in the cities' energy systems has increased, especially after 1995. Natural gas is a cleaner source of energy that contributed 10%, 3%, 4%, and 16% to the final energy consumption of Beijing, Shanghai, Tianjin, and Chongqing in 2006, respectively, but the share of natural gas to the total CO_2 emissions are close to half of their energy share, i.e., 5%, 1.6%, 2%, and 8%, respectively (Fig. 5). Chongqing is prominent in the utilization of natural gas. In 1997, natural gas contributed 14% of the final energy consumption, while in other cities, its utilization had just begun. Beijing, in particular, rapidly developed an infrastructure for natural gas in a short period of time; until 1997, its share was only 0.8% of the total final energy consumption, which has increased to 10% in 2006.

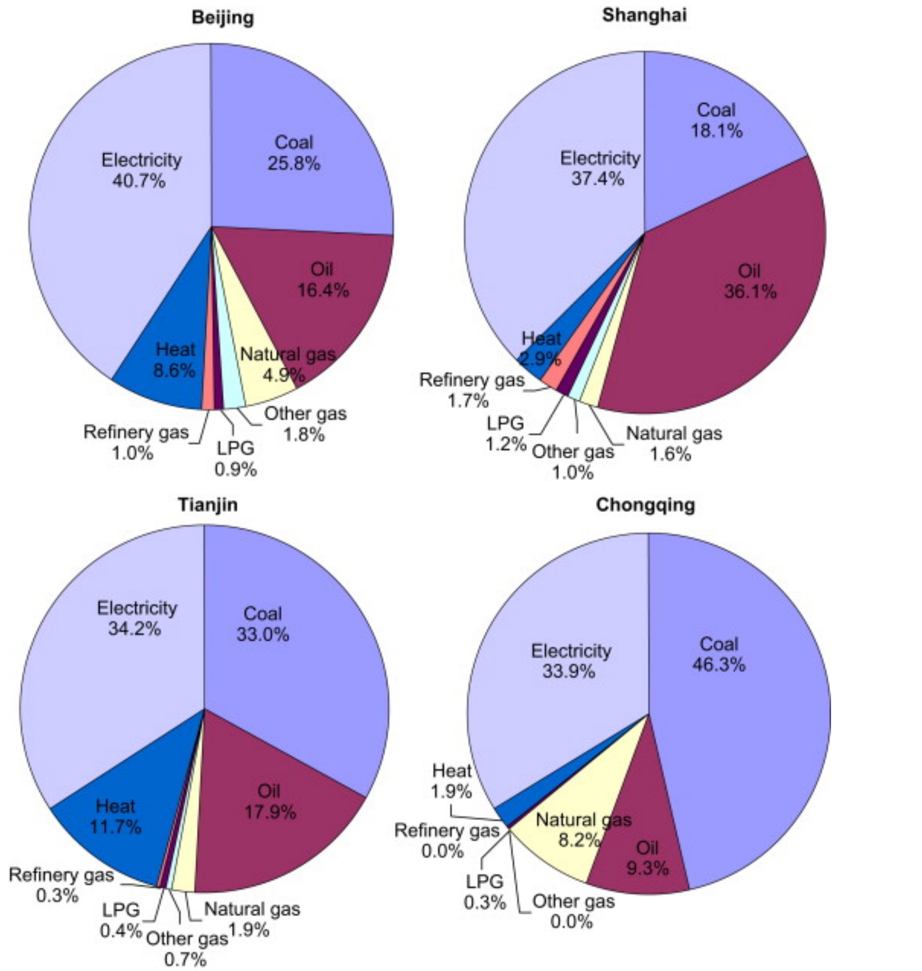

Fig. 5.

Contribution of various fuel types in energy-related CO_2 emissions in 2006. *Note*: It should be noted that a majority of electricity and heat comes from coal as a primary energy.

Figure options

3.2.2. Underlying drivers

Analyses of the driving factors of CO_2 emissions from energy uses can be performed by different methods. At the macro-scale, factor decomposition, vector auto regression (VAR), correlation analysis (see Yuan and James, 2002), and other methods can analyze the roles of various factors. The factor decomposition method is a useful tool for understanding historical changes. Several studies have used factor decomposition analysis. Ang and Zhang (2000) surveyed and cited over 100 published studies that used decomposition analyses for energy and environmental studies. In our study, we reviewed many studies, particularly those by Shrestha and Timilsina, 1996 and Shrestha and Timilsina, 1998, Ang and Liu (2001), Greening et al. (1998), Luukkanen and Kaivooja (2002), Nag and Parikh (2000), and Hamilton and Turton (2002). Our choice of technique is a simple subtractive decomposition that follows Sun (1998), Luukkanen and Kaivooja (2002), and Dhakal et al. (2002). In this method, the emissions between two given years are decomposed to show the effects of four factors: demographic effect, income effect, energy-intensity effect, and fuel transition effect. For example, the energy-intensity effect is the changes in CO_2 emissions that would have resulted only from changes in the energy intensity with other factors remaining constant. This method is illustrated in the Appendix. The results of the decomposition analyses are presented in Fig. 6, where the relative contributions of these factors to the changes in CO_2 emissions in a designated period are scaled to 1.

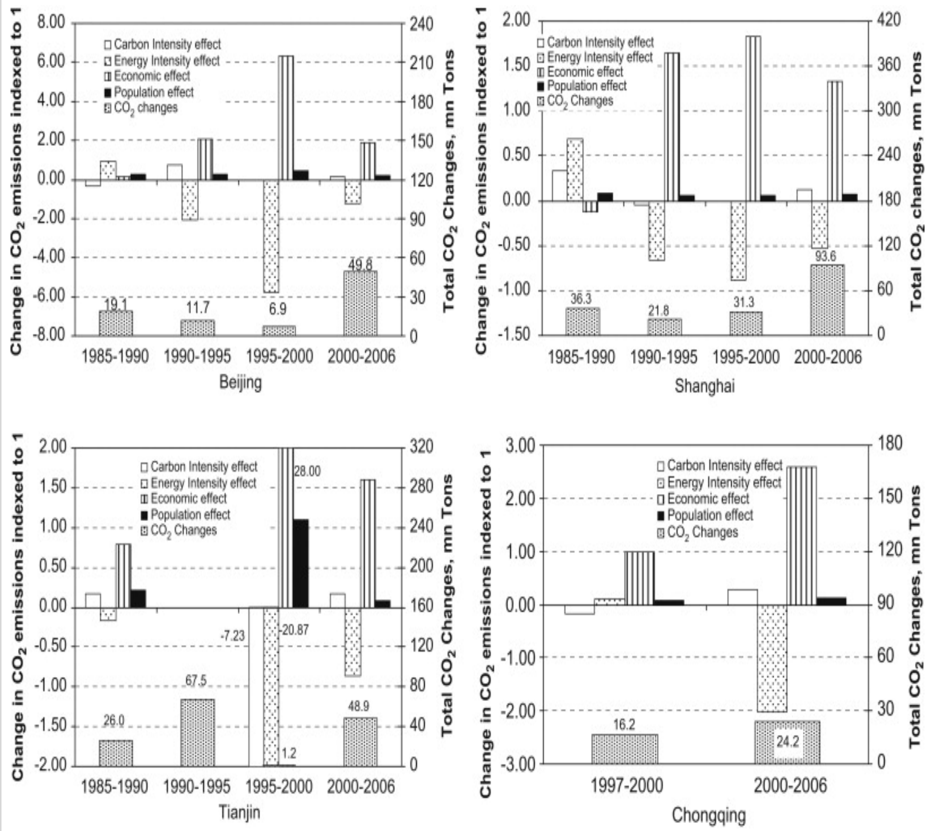

Fig. 6.

Contribution of factors to the changes in CO_2 emissions in cities.

Figure options

The results show that the economic growth and energy intensity have dominant effects on the changes in CO_2 emissions in all cities. Economic growth drove CO_2 emissions, but energy intensity dampened the CO_2 growth. The forces of contributing factors from 1995 to 2000, in particular, were very intense, as this period was marked by slowdowns in emission growths in the cities and for China as a whole. In addition, the impacts of fuel shifts to the changes in CO_2 emissions are nominal in these cities due to the dominance of coal and oil. The shift to cleaner fuels is not significant and thus has not contributed to the dampening of CO_2 growth despite the perceived impression that the role of natural gas is rapidly expanding in Chinese cities' energy systems. Moreover, our analyses show that the carbon emitted per unit of energy consumption is slightly increasing in the cities. In Fig. 6, the population effect has contributed to increased CO_2 emissions consistently over the years. When we used the resident population in the analyses, the impact of population to the changes in CO_2 emissions was found to be much higher than in Fig. 6.

3.2.3. Carbon-economy performance

Based on the earlier estimations, the cities' historical changes in terms of carbon intensity of economic activities and per capita CO_2 emissions are shown in Fig. 7. This figure illustrates several key observations regarding the urban energy and CO_2 transitions in the cities. It shows that the per capita CO_2 emissions in these cities have increased relentlessly over the last two decades with the rapid economic growth. The carbon intensity of the economic activities in these cities peaked in the 1990s, when economic growth started to accelerate but energy efficiency did not improve. Therefore, Fig. 6 shows that energy intensity contributed more to increasing emissions than to dampening them in the period 1985–1990. However, throughout the 1990s, cities' reductions in the carbon intensity coincided with the strong growth in tertiary sectors (Fig. 8) and the strong role of energy efficiency in dampening the growth of CO_2 emissions (Fig. 6). Since the early 2000s, the improvement in carbon intensity of economic activities has slowed in these cities, and, in the last few years, it has started to worsen in some cities. Fig. 8 shows that the growth in the share of the tertiary sector has considerably slowed down too in the period 2000–2006 as compared with earlier decades for Beijing and Chongqing, but it became negative for Shanghai and Tianjin, which is unprecedented in the last 25 years.

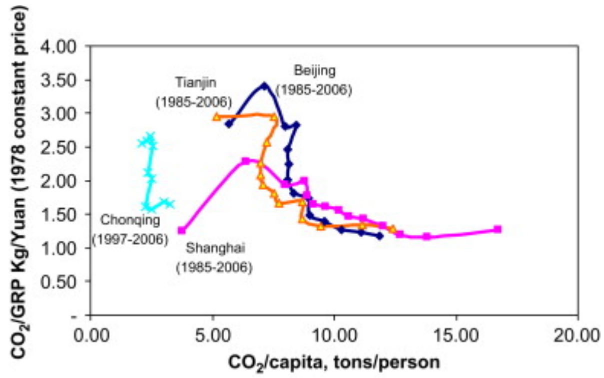

Fig. 7.

Carbon-economy performance.

Figure options

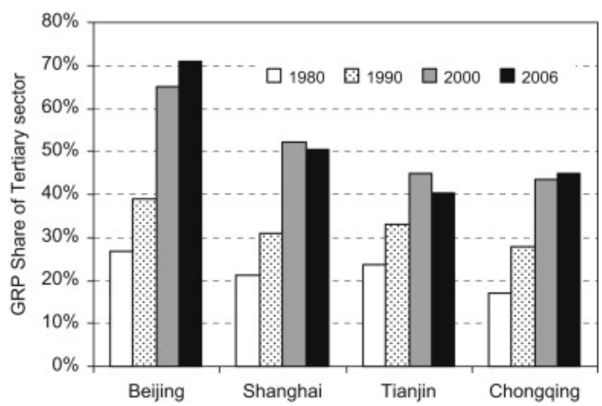

Fig. 8.

Share of tertiary sector.

Figure options

4. Conclusions and policy implications

This paper had three aims. The first was to show the urban contribution to China's energy uses and to highlight their importance in determining the energy and carbon profiles of the nation. The second was to show the internal dynamics of urban areas in relation to energy usage and CO_2 emissions at the meso-scale by estimating and analyzing the highly urbanized and economically most important cities. The third was to illustrate the historical changes in urban energy uses and CO_2 emissions and their drivers in urban areas at the micro-scale through a detailed analysis of Beijing, Shanghai, Tianjin, and Chongqing. Although these four cities may not be a representative case, they represent the rapid urbanization, economic growth, and the accelerated changes in technology, lifestyle, and societal transformation. This three-tier analysis—at the national scale, meso-scale, and micro-scale—illustrates the considerable implications for key policies such as energy efficiency and climate change mitigation in China.

Our analysis showed that the urban contribution to China's total commercial energy uses was 84% in the year 2006. Given such a high contribution, the resulting gap between the urban and the rural contribution has become large. Thus, the ratio between urban to rural per capita commercial energy uses is 6.8. Similarly, the ratio of urban to national per capita commercial energy uses is 1.9. If we account for non-commercial energy uses such as bio-mass, waste, and other renewable sources with the assumption that urban areas only use commercial energy, then the urban contribution to China's total energy usage would be 75% in the year 2006. Since the per capita energy uses in highly urbanized cities are rising and the rate of urbanization itself is rapid, it is inevitable that the urban contribution will increasingly determine China's energy uses and CO_2 emissions for the next few decades. Therefore, this calls for a comprehensive national strategy and guidance by the national government of cities for integrated planning for urban development and energy efficiency. This is especially important because urban development led by individual cities in China has been rampant with few considerations to local socio-economic and environmental considerations, let alone the concerns for energy security and climate change mitigation.

Our analysis of the 35 cities in China that represent provincial capitals and cities mentioned in the national plan shows that they have a disproportionate influence on China's energy and economic activities. We showed that these highly urbanized and economically important cities had merely 18% of China's population but produced 41% of GDP, consumed 40% of commercial energy, and contributed 40% of CO_2 emissions in the year 2006. This shows that the population share of large cities may be small but that large cities' energy and CO_2 impacts are disproportionately large in the context of developing countries. This also counters the argument that larger cities are getting unfair attention despite having a smaller share of the population. We show that the large cities could be a primary target for improving the energy security and for climate change mitigation in China. Among these cities, we observed three energy–economy pathways: the high, low, and middle. The energy-intensive cities are largely located in the central and western parts of China, which house energy-intensive industries and lie in climatically cooler areas. The less energy-intensive cities are located in the eastern part of the country. They are closer to the coast and have strong service industries and a relatively warmer climate. This highlights the fact that these urban regions with higher energy consumption deserve considerable attention for better technologies, more investment, and improved urban energy systems and infrastructure.

Our analysis of the four mega-cities of China, Beijing, Shanghai, Tianjin, and Chongqing, revealed a number of interesting facts regarding urban energy uses and CO_2 emissions. It showed that the energy uses and CO_2 emissions have increased several-fold, with the industrial sector contributing to the most in the last two decades alongside rapid economic growth. It also revealed that the average per capita urban energy use of China is small, but in the case of key cities such as Beijing (11.9 tons/registered person), Shanghai (16.7 tons/registered person), and Tianjin (12.4 tons/registered person), these emissions are well above other key cities in the developed world, such as Tokyo (5.9 tons/person for 2003; TMG, 2006), Greater London (6.95 tons/person for 2003, TMG, 2006), and New York City (7.1 tons/person for 2005, PLANYC, 2007).

Historically, a number of other key changes have taken place in urban energy and CO_2 emissions in China. The first is the declining share of the industrial sector and the gradually increasing commercial and transportation sectors. The second is the declining share of direct coal burning (or its variants such as briquettes and coke) with gradually rising shares of electricity and oil. The third is the rising share of cleaner fuel, mainly natural gas, but this transition has been much slower for many cities. Our analyses also showed that economic growth and energy intensity have played key roles in increasing and dampening of CO_2 emissions, respectively. The role played by the fuel shift is nominal, but the demographic effect has played an important role in increasing emissions in cities such as Shanghai and Beijing, where there are large unregistered or floating populations. Our observations show that cities' CO_2 emissions per capita have increased over the years but their carbon intensity of economic activities have dramatically in the last decades. Unfortunately, in the last few years, the improvements to the CO_2 intensity have either significantly slowed down or have become negative in a few cities due to the slacking in the expansion of the tertiary sector and the over reliance on the traditional coal-based economy. The negative implications of CO_2-intensity trends, which originate from energy intensity, are obvious for the 20% reduction in energy intensity set by the 11th Five Year Plan and the climate change mitigation strategies that heavily rely on the better performance of the energy sector.

Lastly, this study also experienced that the information base for urban-scale energy analyses is poor in China. In this study, due to the unavailability of energy data of cities, the urban contribution to China's energy consumption was calculated from a methodology that was relatively weaker. This is also the case for the contribution of 35 cities of China. However, since this is an area, which is less-studied in entire literature, the motivation of this study was to get an idea on the extent of urban contribution and their policy implications. However, there is a large scope to improve and carry out further detailed studies with better methodologies as a follow-up of this in the future.

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Appendix A. Decomposition method used

$$C=C/E\times E/GRP\times GRP/P\times P=CI\times EI\times PC\times P$$

where C is the total emissions in thousands of tons, E is the total energy consumption (final energy consumption plus losses and transformations) in TJ, GRP is the gross regional product in million 1978

Yuan, and P is population in million. C/E is defined as the carbon intensity (CI), E/GRP by energy intensity (EI), and GRP/P by per capita GRP (PC). I, EI, PC, and P are explanatory variables. The increase in emissions in year t from year 0 is

$$C_t - C_0 = CI_t \times EI_t \times PC_t \times P_t - CI_0 \times EI_0 \times PC_0 \times P_0$$

If we denote the increment amount by Δ, then

$$\Delta C = (CI_0+\Delta CI)\times(EI_0+\Delta EI)\times(PC_0+\Delta PC)\times(P_0+\Delta P) - CI_0\times EI_0\times PC_0\times P_0 = \Delta CI\times EI_0\times PC_0\times P_0 \ldots\ldots(1) + CI_0\times\Delta EI\times PC_0\times P_0 \ldots\ldots(2) + CI_0\times EI_0\times\Delta PC\times\Delta P \ldots\ldots(3) + CI_0\times EI_0\times PC_0\times\Delta P \ldots\ldots(4) + R \ldots\ldots(5)$$

where

$$R = \Delta CI\times\Delta EI\times PC_0\times P_0 + \Delta CI\times EI_0\times\Delta PC\times P_0 + \Delta CI\times EI_0\times PC_0\times\Delta P\times\Delta CI\times\Delta EI\times\Delta PC\times P_0 + \Delta CI\times\Delta EI\times PC_0\times\Delta P + \Delta CI\times EI_0\times\Delta PC\times\Delta P + \Delta CI\times\Delta EI\times\Delta PC\times\Delta P + CI_0\times\Delta EI\times\Delta PC\times P_0 + CI_0\times\Delta EI\times PC_0\times\Delta P + CI_0\times\Delta EI\times\Delta PC\times\Delta P + CI_0\times EI_0\times\Delta PC\times\Delta P$$

We distributed the residual terms R to (1)–(4) in such a way that

$$\begin{aligned}\text{CI effect} = {} & \Delta CI \times EI_0 \times PC_0 \times P_0\\ & + \tfrac{1}{2}\times \Delta CI \times \Delta EI \times PC_0 \times P_0\\ & + \tfrac{1}{2}\times \Delta CI \times EI_0 \times \Delta PC \times P_0\\ & + \tfrac{1}{2}\times \Delta CI \times EI_0 \times PC_0 \times \Delta P\\ & + \tfrac{1}{3}\times \Delta CI \times \Delta EI \times \Delta PC \times P_0\\ & + \tfrac{1}{3}\times \Delta CI \times \Delta EI \times PC_0 \times \Delta P\\ & + \tfrac{1}{3}\times \Delta CI \times EI_0 \times \Delta PC \times \Delta P\\ & + \tfrac{1}{4}\times \Delta CI \times \Delta EI \times \Delta PC \times \Delta P\end{aligned}$$

$$\begin{aligned}\text{EI effect} = {} & CI_0 \times \Delta EI \times PC_0 \times P_0\\ & + \tfrac{1}{2}\times \Delta CI \times \Delta EI \times PC_0 \times P_0\\ & + \tfrac{1}{2}\times CI_0 \times \Delta EI \times \Delta PC \times P_0\\ & + \tfrac{1}{2}\times CI_0 \times \Delta EI \times PC_0 \times \Delta P\\ & + \tfrac{1}{3}\times \Delta CI \times \Delta EI \times \Delta PC \times P_0\\ & + \tfrac{1}{3}\times \Delta CI \times \Delta EI \times PC_0 \times \Delta P\\ & + \tfrac{1}{3}\times CI_0 \times \Delta EI \times \Delta PC \times \Delta P\\ & + \tfrac{1}{4}\times \Delta CI \times \Delta EI \times \Delta PC \times \Delta P\end{aligned}$$

$$\begin{aligned}\text{Income effect} = {} & CI_0 \times EI_0 \times \Delta PC \times P_0\\ & + \tfrac{1}{2}\times \Delta CI \times EI_0 \times \Delta PC \times P_0\\ & + \tfrac{1}{2}\times CI_0 \times \Delta EI \times \Delta PC \times P_0\\ & + \tfrac{1}{2}\times CI_0 \times EI_0 \times \Delta PC \times \Delta P\\ & + \tfrac{1}{3}\times \Delta CI \times \Delta EI \times \Delta PC \times P_0\\ & + \tfrac{1}{3}\times \Delta CI \times EI_0 \times \Delta PC \times \Delta P\\ & + \tfrac{1}{3}\times CI_0 \times \Delta EI \times \Delta PC \times \Delta P\\ & + \tfrac{1}{4}\times \Delta CI \times \Delta EI \times \Delta PC \times \Delta P\end{aligned}$$

$$\begin{aligned}\text{Population effect} = {} & CI_0 \times EI_0 \times PC_0 \times \Delta P\\ & + \tfrac{1}{2}\times \Delta CI \times EI_0 \times PC_0 \times \Delta P\\ & + \tfrac{1}{2}\times CI_0 \times \Delta EI \times PC_0 \times \Delta P\\ & + \tfrac{1}{2}\times CI_0 \times EI_0 \times \Delta PC \times \Delta P\\ & + \tfrac{1}{3}\times \Delta CI \times \Delta EI \times PC_0 \times \Delta P\\ & + \tfrac{1}{3}\times \Delta CI \times EI_0 \times \Delta PC \times \Delta P\\ & + \tfrac{1}{3}\times CI_0 \times \Delta EI \times \Delta PC \times \Delta P\\ & + \tfrac{1}{4}\times \Delta CI \times \Delta EI \times \Delta PC \times \Delta P\end{aligned}$$

such that

$$C = \text{CI effect} + \text{EI effect} + \text{Income effect} + \text{Population effect}$$

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1 MGI (2008) showed that migration will emerge as the clear driver of future urbanization (p. 16). It will be responsible for 70% of urban population growth in 2005–2025; the remainder will be by city expansion, new cities, and organic growth. In 2025, the existing migrants as of 2005 and new migrants will make up 40% of the total urban population.

2 These cities are: Beijing, Tianjin, Shijiazhuang, Taiyuan, Hohhot, Shenyang, Dalian, Changchun, Harbin, Shanghai, Nanjing, Hangzhou, Ningbo, Hefei, Fuzhou, Xiamen, Nanchang, Jinan, Qingdao, Zhengzhou, Wuhan, Changsha, Guangzhou, Shenzhen, Nanning, Haikou, Chongqing, Chengdu, Guiyang, Kunming, Xi’an, Lanzhou, Xining, Yinchuan, and Urumqi.