China's regional carbon emissions change over 1997-2007

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Abstract
The increased demand for energy in China has generated concomitant increase of carbon emissions, which poses an unprecedented challenge to China's, and even global, sustainable development. In this paper, from the perspective of provincial carbon emissions, we analyze China's carbon emissions changes during 1997-2007 based on the index decomposition analysis method. We find that: (1) China's CO_2 emissions from end-use energy consumption mainly originated from such major industrial provinces as Hebei, Jiangsu, Zhejiang, Shandong, Henan and Guangdong. (2) Economic growth and decline in energy intensity will have the greatest impact on CO_2 emissions from end-use energy consumption. Economic growth is the key factor driving the increase of CO_2 emissions. Change in energy intensity can more or less decrease CO_2 emissions. In the future, China's carbon emissions mitigation policies should be developed to address these differences in provincial carbon emissions.
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1. Introduction
Next to the United States, China is the greatest source of greenhouse gas emissions in the world, and has been one of bigger contributors to the rapid growth of global CO_2 emissions in recent years, accounting for 44% of the increase in global CO_2 emissions in 1990–2004 [1]. Moreover, in the very short period 2002 – 2007, China's CO_2 emissions almost doubled as its economy continued to expand rapidly, with carbon intensity presenting an upward trend.
To understand the evolution of Chinese CO_2 emissions, many studies have used the index decomposition analysis (IDA) method to analyze China's national carbon emissions and carbon intensity change (e.g. [2-7].
Wu et al. [2] argued that the rate of decline in energy intensity and slowdown in growth of average labor productivity in the industrial sectors were the dominant contributors to the sudden changes in energy-related CO_2 emissions in the period 1996-1999. Wu et al. [3] used the Log-mean Divisia Index (LMDI) method to study CO_2 emissions from 1980-2002, and concluded that before 1996, economic scale, fuel mix and energy intensity on the energy-demand side mainly drove the changes in China's CO_2 emissions, with the structure and efficiency changes on the energy-supply side playing only a minor role. Moreover, over the period 1996-2000, the acceleration of efficiency improvement in end-use and the transformation sectors (i.e. power. generation, oil refinery, and coal production) accounted for the decline in China's

CO_2 emissions related to the total primary energy supply. Wang et al. [4] concluded, based on the LMDI method, that the total theoretical decrease of CO_2 emissions was 2466 MtC during 1957-2000, of which about 95% of the total decrease could be attributed to energy intensity decline, and only 1.6% and 3.2% to fossil fuel mix and renewable energy penetration, respectively. Fan et al. [5] show that industry structure partly offset the decline over the period 1987-2002, and the change in final-energy-mix partly offset the decline in carbon intensity over the period 1981-2002, suggesting that final-energy use in the material production sectors and development of the material production sectors became carbon-intensive. Therefore, further decline in carbon intensity should focus on the material production sectors' final-energy use, especially the industrial sectors. Liu et al. [6] analyzed the industrial carbon emissions changes, finding that raw chemical materials and chemical products, nonmetal mineral products and smelting and pressing of ferrous metals accounted for 59.31% of total increase of industrial CO_2 emissions. Therefore, the overwhelming contributors to the change in China's industrial sectors' carbon emissions in the period 1998-2005 were industrial activity and energy intensity. The impact of the emissions coefficients of heat and electricity, and fuel and structural shifts was relatively small. Zhang et al.[7] analyze the nature of the factors that influence the changes in energy- related CO_2 emission and CO_2 emission intensity during the period 1991–2006, and find that: energy intensity effect is confirmed as the dominant contributor to the decline in CO_2 emission and CO_2 emission intensity, and economic activity is the most important contributor to increased CO_2 emission.

These aforementioned studies show that China's economic growth and energy intensity are two important and key factors to effect the change of China's carbon emissions or carbon intensity, and the impacts of other factors (fuel mix, economic structure and carbon coefficient) are relative less, but their impact can not be ignored. However, all these studies focus on the analysis of national carbon emissions, and there have been no systematic empirical studies on the analysis of provincial CO_2 emissions, in particular, how they have changed over time. An exception is Auffhammer and Carson [8], who forecast China's carbon emissions based on provincial carbon emissions.

For China, there exist obvious differences in economic growth, size, population, energy use and energy efficiency across provinces, and some key indicators in every province were shown in Appendix A, which have led to great differences in energy consumption, mix and carbon emissions. This raises the following questions: (1) Which provinces are mainly responsible for China's total carbon emissions? (2) What are the provincial characteristics of per capita CO_2 emissions? (3) What are the differences in provincial CO_2 emission intensity? (4) Which factors have an important role in the change of provincial CO_2 emissions? All these questions are important for China's policy makers to understand more about the characteristics of provincial carbon emissions to draw up specific climate policies decisions. Consequently, this paper analyzes China's provincial CO_2 emission change over the period 1997-2007 aiming to provide answers.

The article is organized as follows. Section 2 describes the LMDI method and the data used. Section 3 presents the provincial carbon emissions characteristics. Section 4 shows the impact of different factors on the changes of provincial CO_2 emission based on LMDI. The final section presents the conclusions and offers some policy implications.

2. Data source and methodology
2.1 The source of China's regional carbon emissions
In this paper, China's regional carbon emissions are calculated based on the Sectoral Approach recommended by IPCC, which was shown in the Eq. (1):

$$C = \sum_{ij} C_{ij} = \sum_{ij} \delta_j \times EF_j \times O_j \times E_{ij} \qquad (1)$$

where, C is CO_2 emissions from end-use energy consumption of 28 provinces; i refers to the 28 provinces (excluding Hainan, Ningxia, Taiwan and Tibet); j refers to different energy types; C_{ij} is CO_2 emissions from energy j in province i; δ_j is conversion factor of energy j from tons to TJ; EF_j is carbon emissions factor of energy j, the unit is tC/TJ; O_j is the fraction of carbon oxidized of energy j; E_{ij} is the use of energy j in province i.

The fraction of carbon oxidized and carbon emissions factor of different type of energy excluding electricity and heat come from IEA [9]. The conversion factor of energy j from tons to TJ comes from China Energy Statistical Yearbooks 2008 [12].

The carbon emissions from thermal power generation and heat industry are calculated by their fossil energy use input, the fraction of carbon oxidized and their carbon emissions factor. Then we can get the carbon coefficient of total electricity including thermal power, hydro, nuclear and other renewable electricity and heat.

2.2 Decomposition method of China's provincial CO₂ emissions

Researchers and policy makers use various decomposition methods to quantify the impact of different factors on the change in energy consumption and CO_2 emissions. However, there is no consensus among them as to which is the most appropriate decomposition method. Ang [10] compared various index decomposition analyses, and concluded that the LMDI method is the preferred method due to its theoretical foundation, adaptability, ease of use and interpretation of results, among other desirable properties in the context of decomposition analysis.

In order to identify key factors affecting the change of provincial CO_2 emissions, we adopted the LMDI method to decompose CO_2 emissions related to end-use energy consumption of material production sectors into economic growth, economic structure, energy intensity and CO_2 emission coefficients, as indicated in Eq. (2).

$$C_m = \sum_{ik} C_{ik} = \sum_{ik} Q_i \frac{Q_{ik}}{Q_i} \frac{E_{ik}}{Q_{ik}} \frac{C_{ik}}{E_{ik}} = \sum_{ik} Q_i S_{ik} I_{ik} R_{ik} \qquad (2)$$

where, C_m is CO_2 emissions from end-use energy consumption of material production sectors of 28 provinces; C_{ik} is CO_2 emissions from end-use energy consumption of sector k in province i; Q_{ik} is value-added of sector k in province i; Q_i is sum of value-added in province i; E_{ik} is the end-use energy consumption of sector k in province i; R_{ik} is the CO_2 emissions coefficient of end-use energy consumption of sector k in province i; S_{ik} is value-added share of sector k in province i; and I_{ik} is energy intensity of sector k in province i; k refers to the sectors.

Based on the energy balance table in China Energy Statistical Yearbooks, sectors are classified into the agricultural sector; industrial sector; construction, transport, storage, postal & telecommunications services; and wholesale, retail trade & catering services; residential consumption and others. In general, agricultural sector is defined as Primary industry, industry and construction are defined as Secondary industry, and transport, storage, postal & telecommunications services, and wholesale, retail trade & catering services are defined as Tertiary industry. Primary industry, Secondary industry and Tertiary industry are usually defined as the material production sectors. In China, three industries are very different in many aspects, such as energy use, economic growth etc, and economic structure adjustment addressed in national policies often refers to the adjustment of three industries. So we use three-sector decomposition method, i.e. primary industry, secondary industry and tertiary industry.

For detailed LMDI methodology, refer to the Ang [11].

2.3 Data
2.3.1 GDP data of every province
The provincial GDP and corresponding value-added data in every sector are derived from the China Statistical Yearbooks 1998-2008 [12-17]. All data are expressed to 2005 prices based on the value-added in the current prices and their growth rates.

2.3.2 The end-use energy consumption data
Based on China Energy Statistical Yearbooks, the end-use energy consumption in energy balance table of every provinces includes: raw coal, cleaned coal, briquette, other washed coals, coke, coke-oven gas, other coal gases, crude oil, gasoline, kerosene, diesel oil, fuel oil, liquefied petroleum gas (LPG), refinery gas, other petroleum products, natural gas, electricity and heat. Energies inputs for thermal power

generation and heat industry also include the above energies excluding electricity and heat. All these data are derived from China Energy Statistical Yearbooks 1997-1999, 2005, 2006, 2007 and 2008 [12-17]. Since the China Energy Statistical Yearbook does not contain the energy consumption data of Taiwan, Tibet, and lack the energy use data of Ningxia in 2000, 2001, and 2002 and that of Hainan in 2002, so this paper does not include analysis of these four provinces in order to keep consistent discussions and interpretations.

3 Provincial carbon emissions in China
There are great differences in CO_2 emissions related to end-use fossil fuel among provinces.

3.1 Provincial carbon emissions from 1997 to 2007
Total carbon emissions from end-use energy consumption (Carbon emissions in this section include material production sectors, urban and rural household, and other sectors.) are closely related to end-use energy consumption, energy mix and provincial economic growth. Figure 1 shows the provincial carbon emissions from end-use energy consumption in 1997 and 2007.

In 1997, the CO_2 emissions of Liaoning, Hebei, Jiangsu, Shandong, Guangdong, Henan, Shanxi, Heilongjiang and Hubei provinces accounted for 52.64% of total CO_2 emissions related to total end-use energy consumption of 28 provinces (excluding Hainan, Ningxia, Taiwan and Tibet owing to data unavailability). In 2007, the CO_2 emissions of Shandong, Hebei, Jiangsu, Guangdong, Henan, Zhejiang, Shanxi and Inner Mongolia accounted for 57.08%.
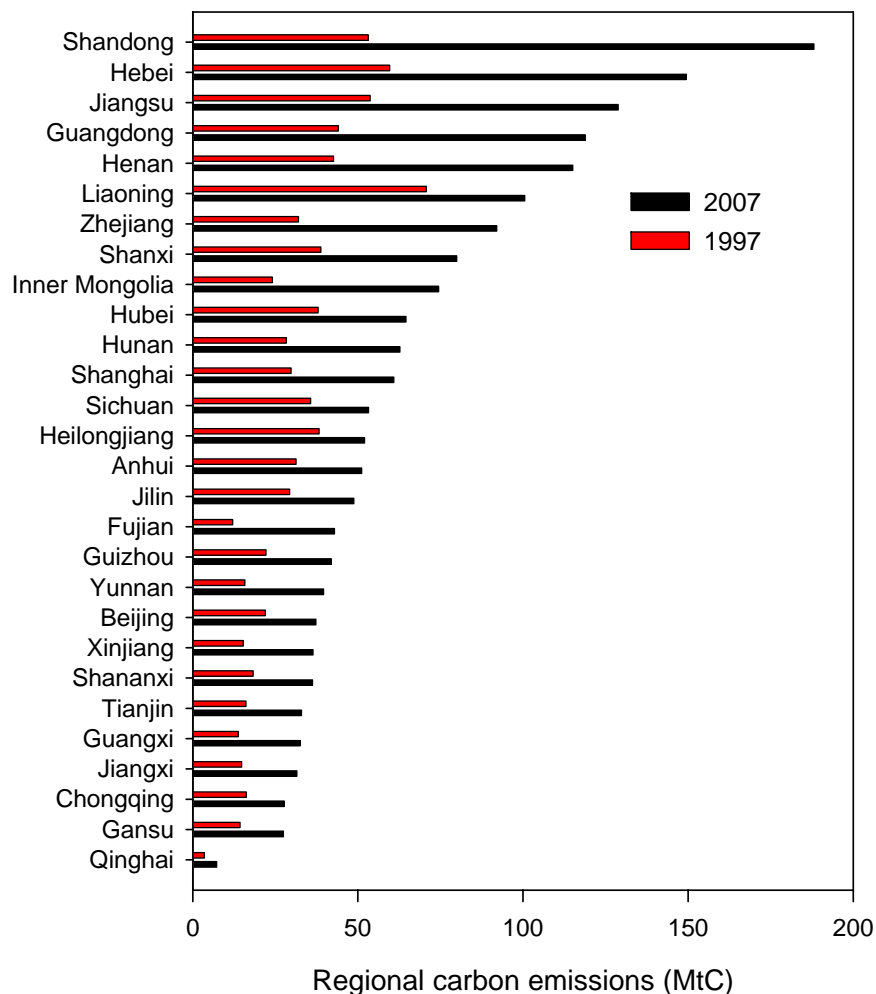

Figure 1. Provincial carbon emissions in 1997 and 2007

Furthermore, compared with 1997, the total CO_2 emissions related to the end-use energy consumption of 28 provinces of China increased by 121.24% in 2007. Shandong, Hebei, Jiangsu, Guangdong, Henan and

Zhejiang provinces were characterized by the greatest increase, being 13.24% , 8.82% , 7.37% , 7.34%

, 7.11% and 5.89%, respectively, and accounting for 49.77% of the total emissions of 28 provinces. Variation in CO_2 emission was closely related to economic development level, especially the industrial development level, as shown in Figure 2.
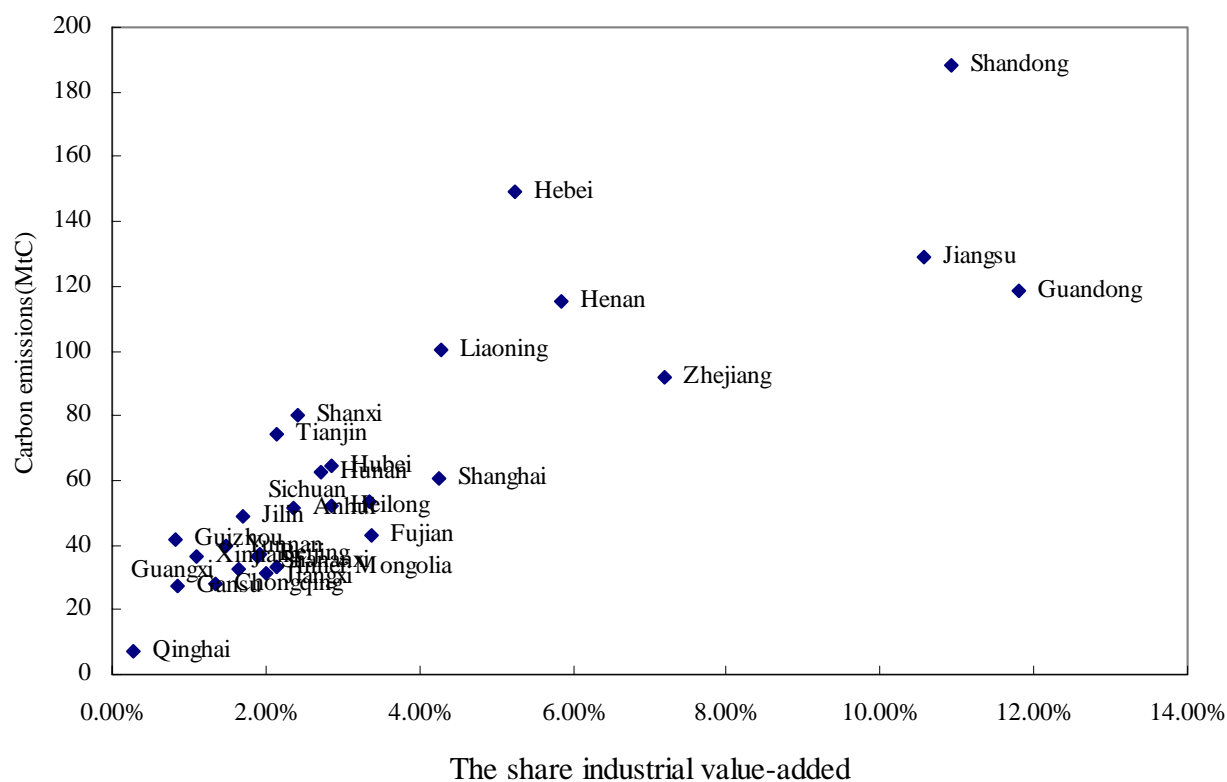

Figure 2. Carbon emissions and the share of industrial value-added in 2007

Guangdong, Shandong, Jiangsu, Zhejiang, Henan and Hebei provinces are top 6 important industrial provinces, whose industrial value-added share in total industrial value-added were 51.59%. Industrial economic growth heavily depends on the demand for energy. This shows that China should pay more attention to their mitigation of CO_2 emissions.

In China, carbon emissions from material production sectors can account for more than 80% of total emissions, which is closely related to China's rapid industrializations. In 2007, China's end-use energy from industrial sector was responsible for 70.45%. Carbon emissions from China's urban and rural residential energy consumption was obviously less than material production sector because China's urban and rural residents' direct commercial energy use per capita was very lower, and up to 2007, 28,000 villages or 7 million families and 30 million rural people still had no power supply in China. In 2007 straw consumption for rural life was 159.79 Mtce and firewood was 92.91 Mtce, totally 252.70 Mtce, much higher than consumption of other commercial energy resources (in 2007 rural consumption of commercial energy resource for living was 100.19 Mtce). So it is necessary to pay more attention to emphasize China's carbon emissions mitigation from material production sectors.

3.2 Provincial growth rate of carbon emissions from 1997 to 2007
The growth rate of provincial carbon emissions reflects the change in carbon emissions across regions However, compared with the emissions increase, the provincial growth rate of carbon emissions in Fujian, Shandong, and Inner Mongolia ranked the top 3, with growth rates of more than 200%. The growth rates of Hebei, Jiangsu, Zhejiang, Henan, Guangdong, Chongqing, Henan, Gansu, and Xinjiang provinces were more than 120%.

Therefore, for major industrial provinces, total carbon emissions, growth and growth rates were all obvious than those of the other provinces. For China, CO_2 emissions mitigation in these provinces became the key.

3.3 Provincial CO_2 emissions per capita from 1997 to 2007
CO_2 emissions per capita can reflect the degree of equality in carbon emissions and energy use. The CO_2 emissions per capita in 28 provinces increased from 0.69 tons of carbon in 1997 to 1.43 tons of carbon in 2007, representing an increase of 0.74 ton per capita. Compared with 1997, the CO_2 emissions per capita of every province increased more or less. The greatest increase was in Shandong, from 0.61 tons of carbon in 1997 to 2.01 tons of carbon in 2007, as shown in Figure 3.
The CO_2 emissions per capita of Beijing, Shanxi, Inner Mongolia and Shanghai were more than 2.5 tons per capita, while those of Anhui, Jiangxi, and Guangxi provinces were still lower than 0.85 ton per capita. For Fujian, Shandong, and Inner Mongolia, the growth rate of carbon emissions per capita from 1997 to 2007 also ranked the top 3 corresponding with the growth rate of total carbon emissions.
And the carbon emissions per capita in 15 provinces (Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Shandong, Xinjiang, Guangdong, Qinghai) in 2007 have been higher than the average level of the world in 2005 (the data of CDIAC shows that in 2005, the average level of the world was 1.23 t C/person), which means that it is necessary to consider specific carbon emissions mitigation policies for different provinces.
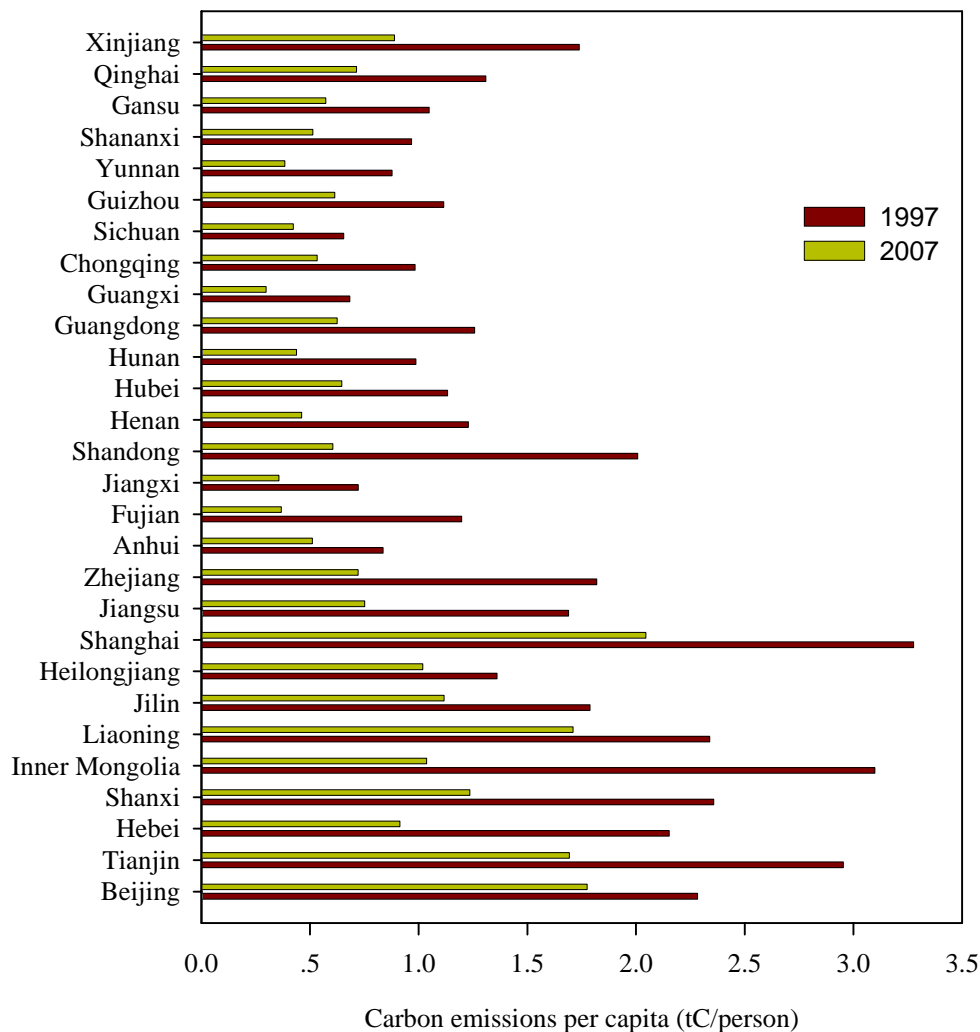

Figure 3. Provincial carbon emissions per capita in 1997 and 2007

3.4 Provincial carbon intensity from 1997 to 2007

Carbon intensity is an important indicator widely used for international and provincial comparisons. Compared with 1997, the CO_2 emission intensity declined in a majority of provinces in 2007 except for Shandong, Yunnan, and Fujian. Significant drops of above 30% took place in Beijing, Tianjin, Liaoning, Jilin, Heilongjiang and Sichuan provinces. Liaoning Province had the greatest drop of 49.53%, as shown in Figure 4.
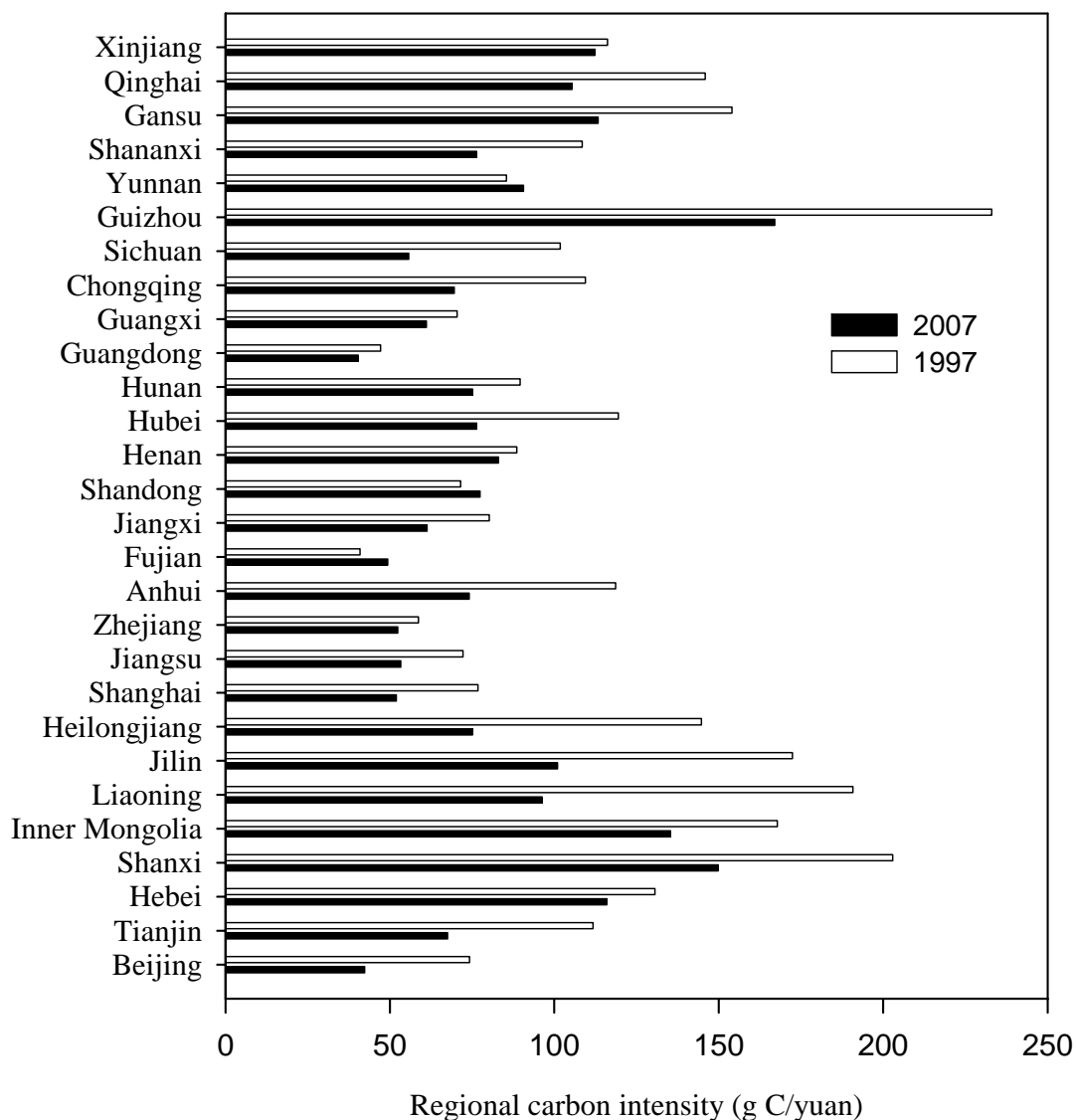

Figure 4. Provincial carbon intensity in 1997 and 2007

The CO_2 emission intensity was high in Shanxi, Inner Mongolia, Guizhou, Gansu, and Qinghai, being even more than 100 gC/yuan in 2007. The highest CO_2 emission intensity was in Guizhou, reaching 167.01 gC/yuan in 2007. The CO_2 emission intensity of Beijing, Shanghai, and Guangdong provinces was on the low side, lower than 60 gC/yuan in 2007. The lowest CO_2 emission intensity was that of Guangdong Province at only 40.44 gC/yuan. The difference in CO_2 emission intensity is closely related to the level of economic development and energy supply, as shown in Figure 5.

However, the decline rate in carbon intensity in those provinces with more carbon emissions was slow, and even rebounded. For example, the carbon intensity increased by 8.22% in Shandong Province, while declining by only 6.40% in Henan Province. Obvious carbon intensity decline mainly occurred in those provinces with less carbon emissions and lower carbon intensity.
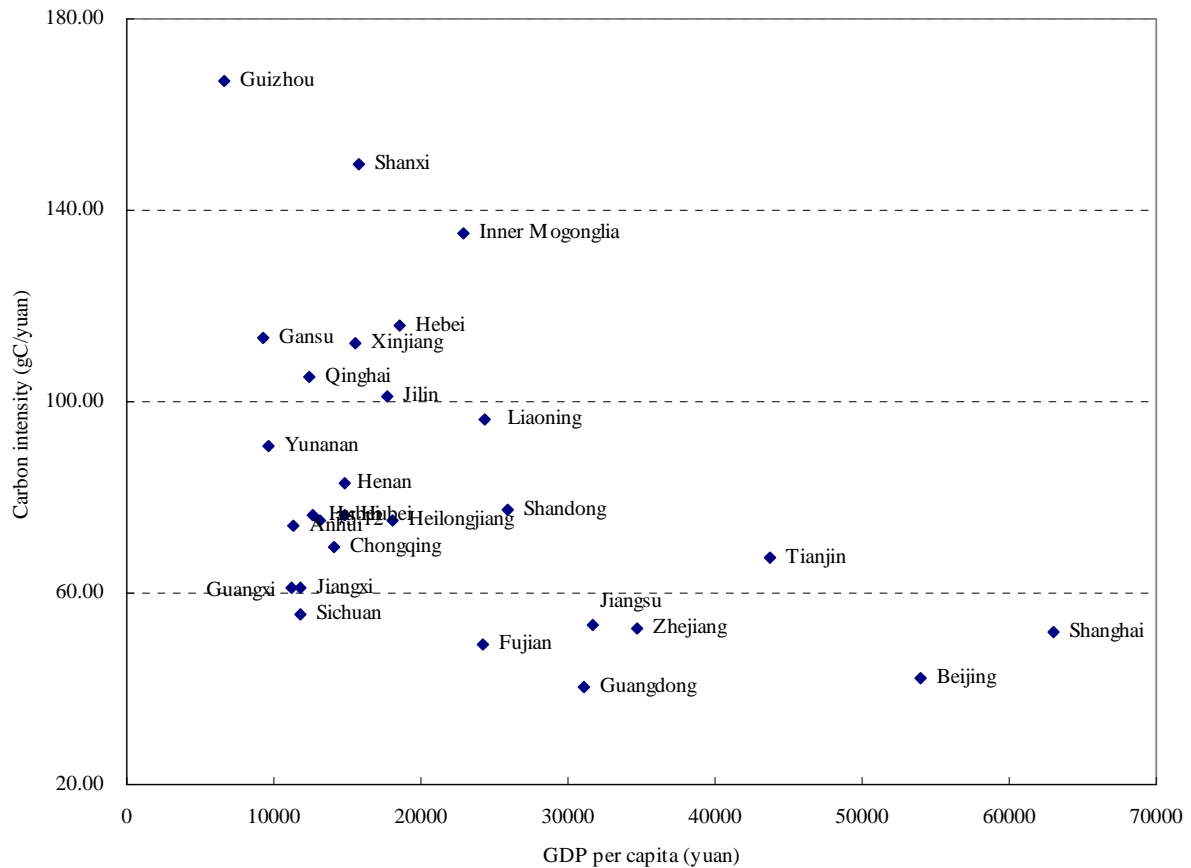
Figure 5. Provincial carbon intensity and GDP per capita in 2007

The above analysis shows us that provincial carbon emissions have obvious characteristics, which can be found in Table 1.

The top five provinces by total carbon emissions from end-use energy consumption are the major industrial provinces with high industrial value-added share. Provinces with high carbon intensity are those with lower GDP per capita and less carbon emissions, and for them, developing economy and alleviating the poverty is first and foremost. So in the future, it is important for China to establish different policy measures to control carbon emissions of different regions.

To control the rapid growth of carbon emissions in Shandong, Hebei, Jiangsu, Guangdong and Henan provinces, we suggest that setting a target for carbon emissions growth in the future years. To minimize the mitigation cost, establishing a voluntary and incentive-based trading scheme may be useful at the basis of China Beijing Environment Exchange, Shanghai Environment and Energy Exchange and Tianjin Climate Exchange. In this market, the permitted allowance is the growth of carbon emissions, other than the absolute carbon emissions.

Table 1. Provincial carbon emissions in 2007

Indicator	Top five provinces
Carbon emissions	Shandong, Hebei, Jiangsu, Guangdong, Henan
Carbon emissions growth rate	Fujian, Shandong, Inner Mongolia, Zhejiang, Henan
Carbon emissions per capita	Shanghai, Inner Mongolia, Tianjin, Shanxi, Beijing
Carbon intensity	Guizhou, Shanxi, Inner Mongolia, Hebei, Gansu

Due to the higher GDP per capita and level of urbanization, to mitigate the growth of carbon emissions in Shanghai and Tianjin provinces, it would be better to establish policies addressing the targets of lower carbon intensity and lower carbon emissions per capita, with focus on low-carbon development.

For Guizhou, Shanxi, Inner Mongolia and Hebei provinces, regions with higher self-supply of coal, policy design should focus on mandatory measures to address energy intensity decline through production technology improvement, energy conservation management and energy efficiency enhancement in larger energy-intensive enterprises.

4. Empirical results and discussions
The above analysis shows that carbon emissions change in China varies across provinces. To identify which factors are driving the change in provincial carbon emissions, we analyzed China's provincial CO_2 emission changes of the material production sectors over the period 1997-2007 based on the LMDI method.

Table 2 shows that the acceleration of CO_2 emissions of 28 provinces varied during 1997-2007. CO_2 emissions grew the fastest during 2003-2007, accounting for 76.38% of the total growth during 1997-2007. Generally, changes in economic growth, industrial structure and CO_2 emission coefficient resulted in increase of CO_2 emissions.

The growth of CO_2 emissions during 1997-2007 was mainly driven by the economic growth of the material production sector and change in industrial structure in 28 provinces. As a result of economic growth, CO_2 emissions in the 28 provinces increased by 1054.53 MtC during 1997-2007. Meanwhile, the increase in the proportion of the secondary industry in the economic structure also resulted in the growth of CO_2 emissions by 120.64 MtC. The increase in carbon emission coefficients helped increase CO_2 emissions by 27.34 MtC. However, the decline in energy intensity also resulted in the decrease of CO_2 emissions by 311.37 MtC, almost equal to the sum of carbon emissions of Shandong and Jiangsu provinces. Therefore, China's CO_2 emissions in 2007 from the end-use energy consumption of the material production sectors of 28 provinces increased by 891.14 MtC over 1997.

Table 2. Impact of various factors on China's carbon emissions during 1997-2007

Period	Change in CO_2 emissions (MtC)	Impact of economic growth (MtC)	Impact of industrial structure (MtC)	Impact of energy intensity (MtC)	Impact of CO_2 emission coefficient (MtC)
1997-1998	-8.06	59.97	7.25	-66.73	-8.55
1998-1999	-0.73	53.66	6.19	-57.30	-3.28
1999-2000	36.04	59.75	9.20	33.38	-66.29
2000-2001	21.96	62.87	6.34	-134.71	87.46
2001-2002	83.59	77.87	9.50	-15.55	11.76
2002-2003	77.66	105.85	9.99	48.76	-86.95
2003-2004	150.87	126.15	14.81	-123.79	133.70
2004-2005	212.31	145.20	17.43	86.35	-36.67
2005-2006	146.77	173.78	19.81	-49.75	2.93
2006-2007	170.73	189.44	20.12	-32.05	-6.77
1997-2007	891.14	1054.53	120.64	-311.37	27.34

4.1 The impact of economic growth on carbon emissions
The rapid economic growth of the material production sector in each province was the major factor driving the increase of CO_2 emissions year by year, as indicated in Table 2. Figure 6 shows the impact of economic growth on CO_2 emissions of 28 provinces.

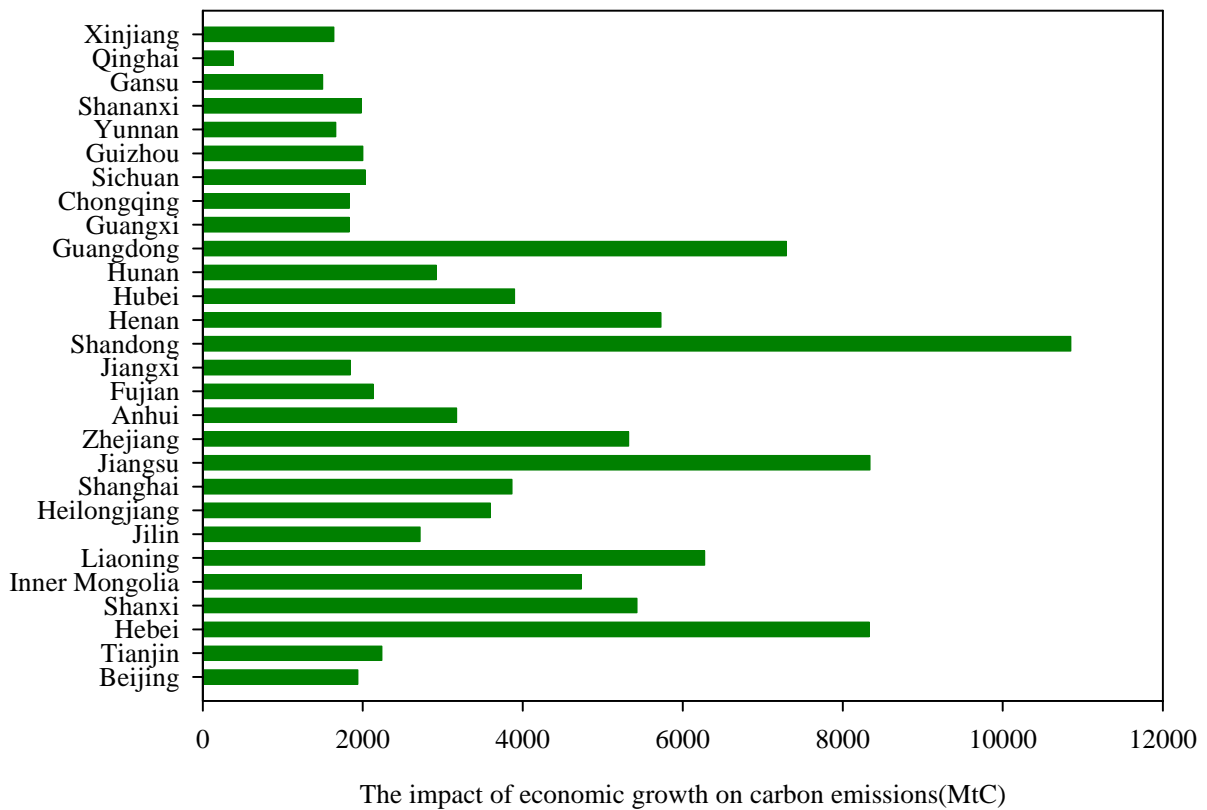The impact of economic growth on carbon emissions(MtC)

Figure 6. The impact of economic growth on provincial carbon emissions

Figure 6 shows us that the economic growth in Hebei, Liaoning, Jiangsu, Shandong, and Guangdong provinces helped increase CO_2 emissions by 83.32, 62.74, 83.38, 108.49, and 72.96 MtC, respectively (410.88 MtC in total, accounting for 38.96% of the overall impact of economic growth on CO_2 emissions). These provinces are not only the major provinces for energy consumption but also for booming economic growth, which contribute 39.33% to national GDP growth, proportional to their impact on carbon emissions. Therefore, the policy makers of these provinces face the challenge of how to coordinate between economic growth and the reduction in CO_2 emissions.

Hebei, Liaoning, Jiangsu, Shandong, and Guangdong provinces are typical export regions, i.e. much of their economic production is exported to meet the final and intermediate production demands of other regions in China and other countries in the world. So carbon emissions caused by their economic growth comprise two parts: the emissions embodied in exported goods; and the emissions meeting the final demand of their own final and intermediate productions. It is difficult to divide these due to the data unavailability. However, this is an important consideration for accounting for emissions and setting targets in the future in these provinces.

4.2 The impact of structural change on carbon emissions
The change in economic structure during 1997-2007 increased CO_2 emissions in China year by year (as indicated in Table 2). Figure 7 shows the impact of economic structural change on CO_2 emissions of 28 provinces.

Only the economic structural change in Beijing and Heilongjiang provinces reduced CO_2 emissions, while such change in all other provinces increased CO_2 emissions, meaning that China's economic structure became carbon-intensive.

In Hebei, Inner Mongolia, Shandong and Henan, the carbon emissions from economic structural change increased 39.79 MtC, accounting for about 32.99% of the total increment of CO_2 emissions caused by economic structural change, mainly attributable to the increase in the share of the secondary sector. Therefore, in these provinces, non-energy-intensive industries should be encouraged and the expansion of energy-intensive industries should be controlled. Meanwhile, the technological transfer of energy-intensive industries should also be strengthened to improve the efficiency of energy use and slow down the growth of energy consumption and CO_2 emissions.
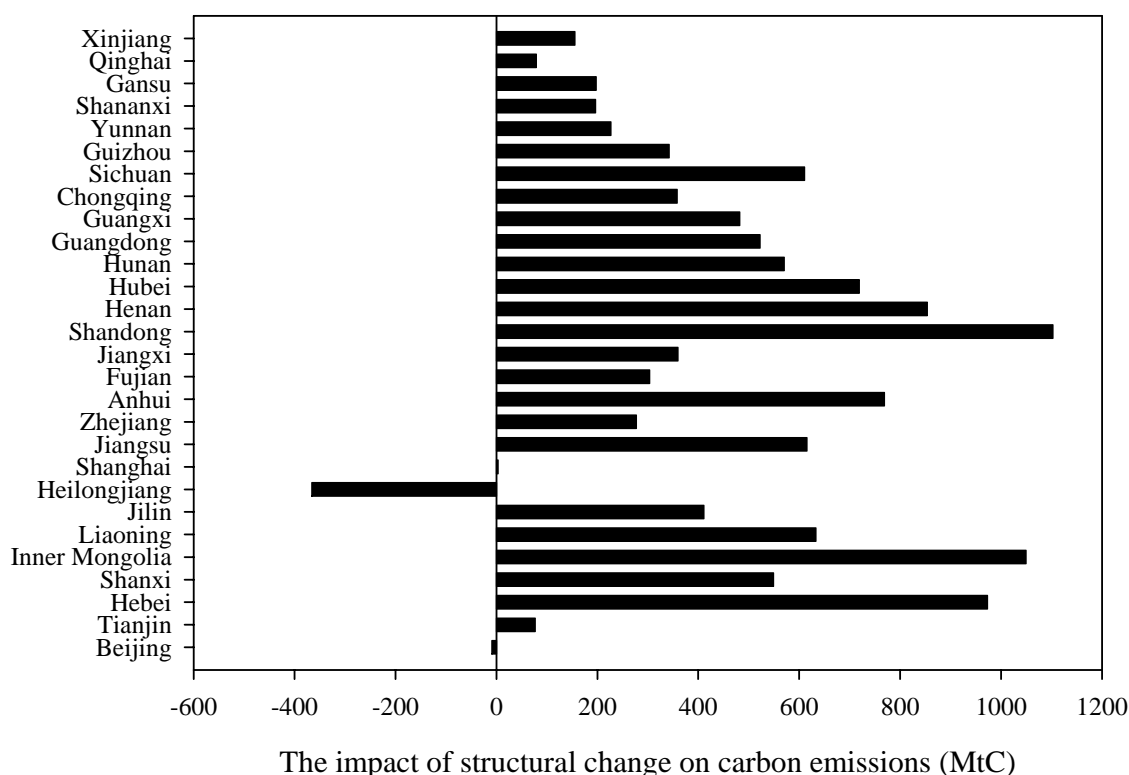
Figure 7. The impact of economic structural change on provincial carbon emissions

4.3 The impact of energy intensity on carbon emissions

Energy intensity is the key factor to mitigate the growth of CO_2 emissions, as shown in Table 2. However, instead of decreasing CO_2 emissions, the impact from energy intensity has resulted in an increase of CO_2 emissions by 48.76 MtC and 86.35 MtC, respectively, during 2002-2003 and 2004-2005, resulting from the rebound of energy intensity in such major industrial provinces as Shandong, Hebei, Jiangsu, Henan and Guangdong.
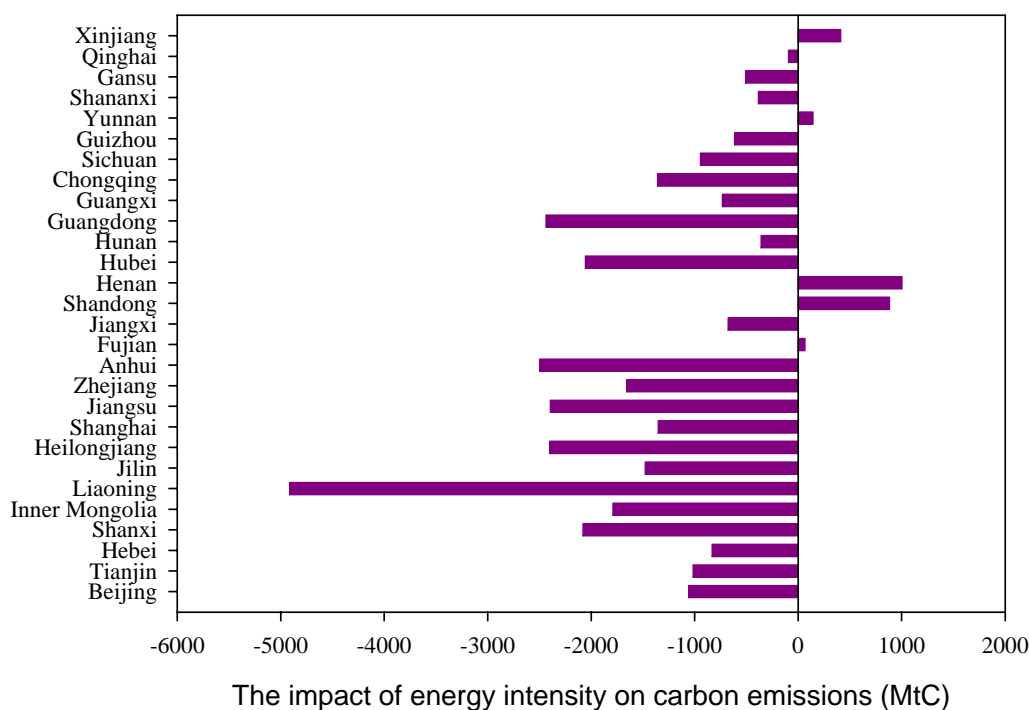

Figure 8. The impact of energy intensity on provincial carbon emissions

Figure 8 shows the impact of energy intensity change on CO_2 emissions during 1997-2007. The energy intensity change in Shandong, Henan, Fujian, Yunnan and Xinjiang provinces resulted in an increase of CO_2 emissions by 25.08 MtC, the greatest increase originating from Henan Province. The energy intensity change in the other provinces reduced CO_2 emissions, the greatest decrease originating from Liaoning Province. Such difference in the impact on CO_2 emission is due to the difference in the change of energy intensity in the secondary sector. The energy intensity of the secondary sector in Henan Province increased by 2.48%, but that in Liaoning Province decreased by 47.78%. Therefore, energy intensity decline in the secondary sector is the key to mitigating the growth of carbon emissions.

4.4 The impact of carbon coefficients on carbon emissions
The impact of the CO_2 emission coefficient on CO_2 emissions not only reflects the impact from the change of the CO_2 emission coefficients of electric power and heat generation, but also reflects the impact from the change in the energy consumption structure, as shown in Figure 9.
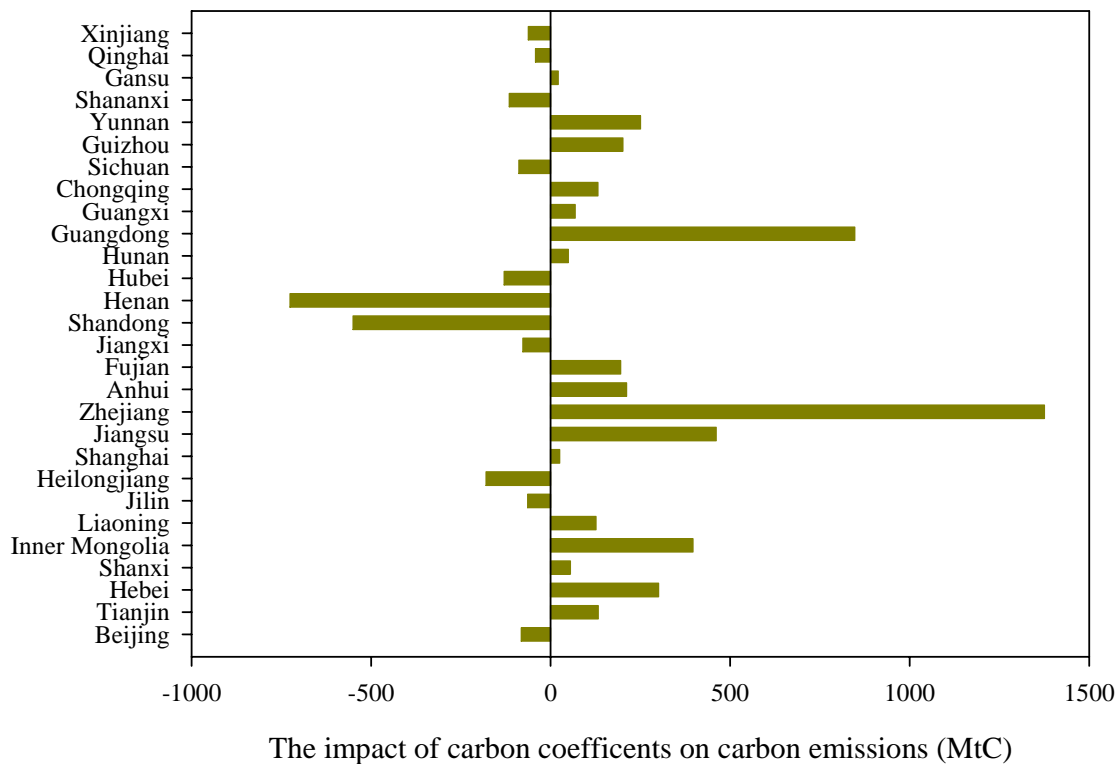

The impact of carbon coefficents on carbon emissions (MtC)

Figure 9. The impact of carbon coefficients on provincial carbon emissions

It can be observed that the impact of the CO_2 emission coefficient is smaller than that of other factors in Table 2. However, this does not present an identical trend. For Zhejiang, Guangxi, Hebei, Yunnan provinces etc., the change of carbon coefficients indicates increases in carbon emissions due to increasing share of electricity, while for others, a reduction in the carbon emissions due to a decline in coal share.

5. Conclusion and policy implications
Due to lack of the detailed data of manufacturing sectors, this paper only analyze regional carbon emissions from three sectors in 28 provinces and can not provide the analysis of carbon emissions from every manufacturing sector in every province. So we can only provide macro-level information for carbon emissions mitigation policy for every province. According to the analysis and empirical research conducted in this paper on provinces in China for 1997-2007, the main conclusions are summarized as follows:
   1. China's CO_2 emissions from end-use energy consumption mainly originated from such major industrial provinces as Hebei, Jiangsu, Zhejiang, Shandong, Henan and Guangdong. Compared with 1997, the total CO_2 emissions from the end-use energy consumption of 28 provinces

increased by 121.24% in 2007. Shandong, Hebei, Jiangsu, Guangdong, Henan and Zhejiang provinces were characterized by the greatest increase of CO_2 emissions from energy end-use, being 13.24% , 8.82% , 7.37% , 7.34% , 7.11% and 5.89%, respectively, accounting for 49.77% of the total emissions of 28 provinces, municipalities and autonomous regions. Therefore, efforts should be focused on these provinces during the mitigation of CO_2 emissions.

2. Differences in provincial economic structure, economic development level and industrial structure result in differences in provincial CO_2 emission intensity, which is high in Shanxi, Inner Mongolia, Guizhou, Gansu, and Qinghai provinces and low in Beijing, Shanghai, and Guangdong provinces.

3. Economic growth and drop in energy intensity will have the greatest impact on CO_2 emissions from end-use energy consumption, and economic development is the key to increasing CO_2 emissions, while change in energy intensity can more or less decrease CO_2 emissions. Despite the slight decrease of CO_2 emission intensity in 2007 over 1997, economic growth contributed to the continual growth of CO_2 emissions in the respective provinces.

The above analysis provides important information for China to draw up different policy measures to control carbon emissions of different regions. We suggest that:

(1) To control carbon emissions in Shandong, Hebei, Jiangsu, Guangdong, Henan provinces, it would be better to set a target for carbon emissions growth. To minimize the mitigation cost, a voluntary and incentive-based trading scheme may be useful. In this market, the permitted allowance would be the growth rate of carbon emissions other than the absolute carbon emissions.

(2) Due to the higher GDP per capita and level of urbanization, to mitigate the growth of carbon emissions in Shanghai and Tianjin provinces, it would be better to establish policies addressing the lower carbon intensity and lower carbon emissions per capita.

(3) For Guizhou, Shanxi, Inner Mongolia and Hebei provinces, regions with higher self-supply of coal, policy design should focus on mandatory measures addressing production technology development, energy conservation management and energy efficiency enhancement in larger energy-intensive enterprises.

The above analysis gives a macro-level analysis for China's regional carbon emissions, but this is not enough for policy-makers to make specific mitigation policies and measures. In the future, we will further analyze the emissions from every industrial source based on the data of the First National Pollution Source Survey. This survey includes detailed information of energy use in every sector in every province.

Appendix A: Some key indications of 30 provinces in 2007

	Population (Million persons)	Size (Thousand square kilometers)	GDP Per capita (Yuan/person, constant 2005 price)	End-use energy consumption (Mtce)
Beijing	16.33	16.8	53934.11	49.06
Tianjin	11.15	11.3	43752.13	36.77
Hebei	69.43	187.7	18573.87	164.77
Shanxi	33.93	156.3	15733.01	93.59
Inner Mongolia	24.05	1183	22887.61	74.93
Liaoning	42.98	145.9	24298.42	118.28
Jilin	27.3	187.4	17704.9	58.12
Heilongjiang	38.24	454.8	18108.69	57.77
Shanghai	18.58	6.3	63071.76	74.29
Jiangsu	76.25	102.6	31691.73	138.55
Zhejiang	50.6	102	34691.32	96.43
Anhui	61.18	139.7	11279.36	58.15
Fujian	35.81	121.3	24256.96	53.08
Jiangxi	43.68	167	11781.5	36.72
Shandong	93.67	153.8	25934.3	204.64
Henan	93.6	167	14818.6	124.95
Hubei	56.99	185.9	14838.16	88.51
Hunan	63.55	211.8	13144.41	81.40
Guangdong	94.49	180	31102.64	145.92
Guangxi	47.68	236	11169.17	44.16
Hainan	8.45	34	13666.58	8.27
Chongqing	28.16	82.3	14140.18	32.82
Sichuan	81.27	481.4	11763.05	77.90
Guizhou	37.62	176	6680.099	49.50
Yunnan	45.14	383.3	9682.693	50.29
Shananxi	37.48	205.6	12666.63	44.45
Gansu	26.17	454.4	9255.51	33.88
Qinghai	5.52	722.3	12428.2	11.62
Ningxia	6.1	66.4	12627.89	17.05
Xinjiang	20.95	1660	15483.85	45.97

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