INTRODUCTION

Global greenhouse gas emissions have become a major concern for the international community, and the increase in CO\textsubscript{2} emissions is the major contributor to the greenhouse effect.\textsuperscript{1,2} According to the report by the Intergovernmental Panel on Climate Change (IPCC), CO\textsubscript{2} emissions from fossil fuel consumption is the main source of CO\textsubscript{2} emissions.\textsuperscript{3} Therefore, controlling energy-related carbon emissions is crucial in implementing emissions reduction policies and achieving low carbon development in many countries.

China has experienced rapid economic development in the last years, which lead to a drastic increase in energy consumption and an increase in CO\textsubscript{2} emissions. China has become the world’s largest emitter of CO\textsubscript{2}.\textsuperscript{4} Facing significant pressure to reduce its carbon emissions, the Chinese government has proposed a series of plans and implemented a range of measures to balance the relationship between economic development and carbon emissions reduction. For instance, before the Copenhagen Climate Conference in 2009, the Chinese central government announced that carbon intensity, namely CO\textsubscript{2} emissions per unit of GDP,
The purpose of this study is to study the energy-related carbon emissions in the provinces and the country from 2005 to 2013, and relative factors leading to the changes as well as relevant contributions. This study conducts a unified calculation of energy-related carbon emissions based on energy balance sheets, and uses the LMDI method for decomposition research on the CO₂ emissions per unit of energy consumption, proportion of industrial energy consumption to total energy consumption, energy consumption per unit of industrial added value, industrial proportion, GDP per capita, and proportion of provincial population. Then the study explores influencing factors and their contributions, and analyzes the underlying causes. The forces
driving provincial CO₂ emissions are discussed and compared with those influencing national CO₂ emissions. Relevant policy implications are proposed.

2 | METHODOLOGY

2.1 | Calculation of energy-related carbon emissions

China does not have direct monitoring data for CO₂ emissions yet. Most research results have been obtained from fossil fuel consumption. The provincial energy consumption statistics for China mainly come from the *China Energy Statistical Yearbook*, and include total provincial energy consumption, energy balance sheet, and provincial energy consumption. Based on the above collection and analysis, provincial energy balance sheets are used in this study to calculate the structure of total provincial energy consumption and energy-related carbon emission in China, and the methods is shown in Figure 1. Provincial total energy consumption data, regional statistics, and 60 years of statistical data for the country from the energy statistics yearbook are used for comparison and reference.

![Figure 1](image-url)  
**Figure 1** Calculation of provincial energy-related carbon emissions

2.1.1 | Consumption of coal, oil, gas, electricity, heat, and other sources of energy

To calculate the total provincial energy consumption and its structure, the first is to obtain the varieties of energy consumption (physical quantity), which is equal to the total final consumption plus loss minus input and output of transformation, according to the provincial energy balance sheets. The total provincial energy consumption of coal, oil, gas, electricity, heat, and other sources is then converted by the standard coal coefficient. The last item, of the varieties of energy, is “other energy sources,” which is considered as heat in this study. Due to the lack of data concerning regional energy heat values, the “Reference coefficient of various energy sources converted into standard coal,” published in the appendix of the *China Energy Statistics Yearbook* in 2014, was adopted uniformly.

2.1.2 | The primary energy consumption for heating power and thermal power

According to the national average consumption coefficient of coal, oil, and gas used for heating, the heating consumption can be converted into the primary energy consumption of coal, oil, and gas. According to the provincial energy balance sheets of coal, oil, and gas used for electricity, the primary energy consumption of coal, oil, and gas per unit of electricity supplied for all provinces can be calculated. According to Formula (1), the provincial electricity emission factor of each province can be calculated as follows:

$$
\text{Provincial electricity emission factor} = \text{Coal consumption for unit electricity supply} \times \text{coalemission factor} + \text{oil consumption for unit electricity supply} \times \text{oil carbon emission factor} + \text{gas consumption for unit electricity supply} \times \text{gas carbon emission factor}
$$

$$
(1)
$$
2.1.3 | Net import electricity
According to provincial energy balance sheets, net import electricity can be calculated as follows:

\[
\text{Net import electricity} = \text{electricity transferred from other provinces} + \text{electricity imported} - \text{electricity transferred to other provinces} - \text{electricity exported}
\]

2.1.4 | Total energy consumption and energy consumption structure
Total energy consumption refers to the energy consumption of all varieties; that is, it is the total consumption of energy but not the total physical quantity consumed; it is based on the Law of Energy Conservation and its unit is tons of standard coal. The calculation is carried out according to the total column in the standard quantity table of the provincial energy balance sheet. At present, the local energy balance sheet is the physical quantity; therefore,

Total energy consumption = sum of terminal energy consumption converted into standard coal + sum of energy processing conversion loss converted into standard coal + sum of energy loss converted into standard coal = sum of energy consumption converted into standard coal − sum of balance difference item converted into standard coal = sum of sources of energy consumption converted into standard coal

According to the levels of consumption of coal, oil, gas, and net import electricity after correction, the data for the primary energy consumption structure and the total consumption of all provinces can be obtained.

2.1.5 | Energy-related carbon emissions
According to Formula (4), the energy-related carbon emissions of all provinces can be calculated as follows:

\[
\text{Energy-related carbon emissions} = \text{coal consumption} \times \text{coal emission factor} + \text{oil consumption} \times \text{oil carbon emission factor} + \text{gas consumption} \times \text{gas carbon emission factor} + \text{net import electricity} \times \text{electricity emission factor}
\]

Based on the previous study and experts’ investigation, the carbon emission factors of coal, oil, and gas were set to 2.64, 2.08, and 1.63 tCO₂/tce, respectively.33 Regional power grid baseline emission factors, published by National Development and Reform Commission, were used to calculate CO₂ emissions from electricity,33-36 and are presented in Table 1.37-39 When the net import electricity were positive, the regional power grid emission factor was used as electricity emission factor; otherwise, the provincial electricity emission factor was used.

2.2 | Decomposition method
The purpose of building the CO₂ emission factor decomposition model is to decompose factors influencing changes in carbon emissions and analyze their influence by calculating their contributions. The changes in total carbon emissions set by this study were caused by already known and explicable factors, such as the provincial energy consumption per unit of industrial added value and provincial energy emission. Ma40 has carried out a research on the contribution of similar decomposition factors to the energy consumption in China.

The formula used to calculate the energy-related carbon emissions in the entire country is as follows:

\[
C = \sum C_i = \sum_i \left[ \frac{C_i}{E_i} \times \frac{E_i^{\text{ind}}}{E_i} \times \frac{V_i^{\text{ind}}}{V_i} \times \frac{P_i^{\text{ind}}}{P_i} \times P \right]
\]

### Table 1 Regional electricity emission factors (tCO₂/MWh): from 2005 to 2013

| Year | North China | Northeast China | East China | Central China | Northwest China | South China |
|------|-------------|----------------|------------|---------------|----------------|------------|
| 2005 | 1.0660      | 1.1649         | 0.9173     | 1.1615        | 1.0849         | 1.0280     |
| 2007 | 0.9725      | 1.0819         | 0.8571     | 1.1020        | 1.0113         | 0.9773     |
| 2009 | 0.9642      | 1.0691         | 0.8129     | 0.9546        | 1.0076         | 0.9172     |
| 2011 | 1.0798      | 1.1546         | 0.7993     | 0.9827        | 0.9404         | 0.9163     |
| 2013 | 0.9913      | 1.1102         | 0.8222     | 0.9291        | 0.9424         | 0.8664     |
The formula for energy-related carbon emissions of province $i$ is as follows:

$$C_i = \frac{C_i}{E_i} \times \frac{E_{\text{ind}}}{E_{\text{ind}}} \times \frac{V_{\text{ind}}}{V_{\text{ind}}} \times \frac{V_i}{V_i} \times \frac{P_i}{P_i}$$

(6)

It should be noted that in this research only 30 provinces, municipalities, and autonomous regions are considered, and Tibet is excluded due to difficulty in basic data acquisition and its low energy consumption and carbon emissions. The definitions of the variables in Formulas (5) and (6) are provided in Table 2.

Ang et al.10,12 showed that the LMDI method uses the results of multiplicative decomposition with an added characteristic, and simultaneously uses multiplicative or additive decomposition, where their results are consistent and can be interconverted.

**2.2.1 Decompose energy-related carbon emissions at national level**

The basic formula for the decomposition of energy-related carbon emissions in the entire country is shown in Formula (5), and the variation in CO$_2$ in year $t$ relative to the base year can be expressed as:

$$\Delta C = C^t - C^0 = \sum_i [F_i^t M_i^t N_i^t I_i^t G_i^t K_i^t P_i^t] - \sum_i [F_i^0 M_i^0 N_i^0 I_i^0 G_i^0 K_i^0 P_i^0]$$

(7)

where $\Delta C$ represents the variation in energy-related carbon emissions in year $t$ relative to the base year, where the unit is MtCO$_2$. $C^t$ and $C^0$ refer to energy-related carbon emissions in year $t$ and the base year, respectively, where the unit is MtCO$_2$, and $\Delta C_F$, $\Delta C_M$, $\Delta C_N$, $\Delta C_I$, $\Delta C_G$, $\Delta C_K$, and $\Delta C_P$ represent the variation in carbon emissions caused by CO$_2$ emissions per unit of energy consumption, the proportion reciprocal of industrial energy consumption in total energy consumption, the energy consumption per unit of industrial added value, the GDP per capita, and the provincial population proportion, and the total population, respectively, where the unit is MtCO$_2$. The LMDI factor decomposition used for Formula (7) is as follows:

$$\Delta C_F = \Sigma W_i \cdot \ln \frac{F_i^t}{F_i^0} \quad \Delta C_M = \Sigma W_i \cdot \ln \frac{M_i^t}{M_i^0} \quad \Delta C_N = \Sigma W_i \cdot \ln \frac{N_i^t}{N_i^0}$$

$$\Delta C_I = \Sigma W_i \cdot \ln \frac{I_i^t}{I_i^0} \quad \Delta C_G = \Sigma W_i \cdot \ln \frac{G_i^t}{G_i^0} \quad \Delta C_K = \Sigma W_i \cdot \ln \frac{K_i^t}{K_i^0} \quad \Delta C_P = \Sigma W_i \cdot \ln \frac{P_i^t}{P_i^0}$$

where $W_i = (C_i^t - C_i^0)/\ln(C_i^t - C_i^0)$.
2.2.2 | Decompose energy-related carbon emissions of each province

The method of decomposition for emissions of province \( i \) was similar to that of the entire country. The formula is as follows:

\[
\Delta C_i = C_i^t - C_i^0 = F_i^t M_i^t N_i^t P_i^t C_i^t - F_i^0 M_i^0 N_i^0 P_i^0 C_i^0 \tag{8}
\]

where

\[
\Delta C_{pi} = \Sigma W_i \cdot \ln \left( \frac{p_i^t}{p_i^0} \right).
\]

2.2.3 | Contribution of influential factors

The contribution of each influential factor was the specific ratio between the variation in carbon emissions caused by the factor and that in total carbon emissions.

2.3 | Data sources

Other than the data sources indicated above, others are mainly from the China Statistical Yearbooks from 2006 to 2014, the provincial statistical yearbooks from 2006 to 2014. The industrial energy consumption of Zhejiang province is based on publication by authorities.41-45 Following the sorting and calculation processes, the basic data for factor analysis of carbon emissions were obtained.

3 | RESULTS

3.1 | Provincial energy-related carbon emissions and carbon emission intensities

The summary of energy-related carbon emissions (MtCO\(_2\)) and carbon intensity (tCO\(_2\)/thousand RMB Yuan) for all provinces in China in 2005 and 2013 is shown in Figure 2.

According to Figure 2, the energy-related carbon emissions of all provinces in China improved at varies levels during this period. The rapid growth in GDP and the effective implementation of energy conservation and emissions reduction measures contributed to the decrease in carbon emissions intensities of all provinces except for Qinghai and Xinjiang.

Many differences were observed based on a comparison of energy-related carbon emissions and the intensities for provinces in China from 2005 to 2013. In terms of \( \text{CO}_2 \) emissions, Shandong recorded as the highest, and Hainan recorded the lowest. Ningxia had the highest carbon intensity, and Guangdong and Beijing had the lowest. These differences were due to many factors. For instance, Shandong ranked first for \( \text{CO}_2 \) emissions due to its large population, GDP, and industrial added value. High energy-consuming industries, such as chemical fiber manufacturing, nonmetallic mineral products, petroleum processing, coking, and nuclear fuel processing contribute significantly to its total emissions. Although the total \( \text{CO}_2 \) emissions of Shandong were the highest, its carbon intensity was relatively low due to its larger economic aggregate. Hainan had the lowest \( \text{CO}_2 \) emissions as its local

![Figure 2](https://example.com/figure2.png)

**FIGURE 2** Energy-related carbon emissions and carbon emissions intensities for each province of China from 2005 to 2013
economy mainly consisted of tourism and its small area and population. The tertiary industry played a dominant role in its industrial structure. Although CO₂ emissions in Ningxia were low, its carbon intensity was the highest owing to the smaller economic aggregate of the province. Although the total emissions of Guangdong ranked fifth in the country, its carbon intensity was low because of its large economic aggregate. In sorting CO₂ emissions and the carbon intensity of provinces from 2005 to 2013, it was observed that there were no significant changes in the rankings for most provinces between 2005 and 2013. Therefore, it is noted that the development situations had co-relation with total CO₂ emissions and the carbon intensity for most provinces in China.

Different results were obtained in identifying the increase rate of CO₂ emissions and the decrease rate of intensity from 2005 to 2013 in each province. The increase rate of CO₂ emissions of Hainan, which had the lowest CO₂ emissions, ranked second at 145.7% during this period. Shandong, with the highest CO₂ emissions, was at the mid-to-low level, and provinces like Beijing and Shanghai had the lowest increase rate of CO₂ emissions. From the perspective of carbon intensity, the top five provinces with the largest decrease rates of carbon intensity were Yunnan, Beijing, Guizhou, Jilin, and Chongqing, whereas Xinjiang, Qinghai, Shaanxi, Shanxi, and Hainan provinces were the last five. According to the division of China’s eastern, central, western, and northeast areas from the National Bureau of Statistics, different increase rates of CO₂ emissions and decrease rates of carbon intensity were observed in both the east and the west. It was evident that although the carbon intensity declined, different provinces in the same area experienced a variety of emissions reduction. For example, Beijing and Hainan, both located in the east of China, had emissions reduction rates of 45.80% and 2.32%, respectively. Similarly, Gansu and Xinjiang, both in the west, had very different emissions reduction rates of 34.22% and −13.70%, respectively. The effects of emissions reduction for different provinces were related to the local economic aggregate, total population, industrial structure, and other variables.

3.2 | Decomposition analysis of China’s CO₂ emissions

According to the factor decomposition model described in Section 2.2, the contribution of factors influencing China’s CO₂ emissions was calculated.

| TABLE 3 | Contribution (%) of factors influencing energy-related carbon emissions at national level: 2005-2013 |
|-------------------------------|----------------------------------|
| Influencing factor | ΔC_F | ΔC_M | ΔC_N | ΔC_I | ΔC_G | ΔC_K | ΔC_P |
| Contribution rate | −2.71 | 11.23 | −135.85 | 1.15 | 212.01 | 2.65 | 11.53 |

According to Figure 3, the total CO₂ emissions of China continued to rise, where continuous rise in GDP per capita was the major factor driving this increase; that is, the continuous rise in total CO₂ emissions was caused by the continuous development, consequently, lead to the rising energy demands of the national economy. Moreover, the proportion reciprocal of industrial energy consumption had a positive contribution to the increase in total CO₂ emissions. However, the reciprocal relationship of this indicator means that the proportion of industrial energy consumption showed a declining trend. The continuous decline in energy consumption per unit of industrial added value slowed down the increase rate of emissions to a certain extent, and its contribution was negative.

In terms of specific performance in Table 3, the contribution of GDP per capita was 212.01%, which coincided with the largest slope of GDP per capita shown in Figure 3. The total population ranked second with a rate of 11.53%, and other positive factors are the proportion of industry and proportion reciprocal of industrial energy consumption to the total energy consumption. The energy consumption per unit of industrial added value made a significant contribution in reducing China’s CO₂ emissions, at −135.85%. CO₂ emissions per unit of energy consumption declined during 2005-2013, which contributed to emissions reduction. GDP per capita and energy consumption per unit of industrial added value have been the key factors in China’s economic development and controlling CO₂ emissions. Although it will be increasingly difficult to control energy consumption per unit of industrial added
value, energy conservation remains the key measure for sustaining China’s development with low carbon emissions in the future. At the same time, the changing trend in total CO2 emissions in China need to be further improved because of its ongoing economic development and improvement in GDP per capita.

3.3 Contribution of factors influencing provincial CO2 emissions

According to the factor decomposition model, the contribution of factors influencing provincial CO2 emissions was calculated. The results are shown in Figure 4 and Table 4.

Similar to the overall national analysis, the factor with the highest contribution to the increase in CO2 emissions in almost all the regions was GDP per capita, whereas energy consumption per unit of industrial added value was the major factor contributing to the decline of CO2 emissions in most provinces. However, various factors showed significant differences due to differences in basic conditions and development in the provinces.

4 DISCUSSION

4.1 The effect of each factor on provincial CO2 emissions

4.1.1 Provincial CO2 emissions per unit of energy consumption

For half of provinces, provincial CO2 emissions per unit of energy consumption played an effective role in reducing CO2 emissions, where there were significant differences. Of all 30 provinces, municipalities, and autonomous regions considered in this study, Yunnan, Beijing, Gansu, and Guizhou were the top four with negative contributions, thereby significantly reducing total CO2 emissions. Conversely, the CO2 emissions of Qinghai, Tianjin, Jilin, and other regions increased because of the rise in CO2 emissions per unit of energy consumption in these provinces. This reflects the variety of energy consumption structure. For instance, Beijing gradually reduced coal consumption during this period and thereby rapidly decreased its CO2 emissions per unit of energy consumption.
As the local energy consumption of Yunnan, Guizhou, and Gansu mostly relied on local non-fossil energy such as hydropower and wind power, their CO$_2$ emissions per unit of energy consumption thus decreased. The proportion of coal consumption of Qinghai and Jilin increased significantly during this period. The change in their energy consumption structure lead to higher CO$_2$ emissions per unit of energy consumption. In Tianjin, the proportion of non-fossil energy used gradually declined during this period, and its CO$_2$ emissions per unit of energy consumption increased.

### 4.1.2 Proportion of industrial energy consumption in total energy consumption

The proportion of industrial energy consumption to total energy consumption is smaller when the value of the proportion reciprocal is large. The proportion reciprocal presented a strong positive contribution in Beijing. This was due to the consumption by its tertiary industries and the lifestyle patterns of its residents instead of that by industry. Heilongjiang and Chongqing accelerated the transformation of their industrial structure, and their proportions of industrial energy consumption continued to decline. And its proportion reciprocal increased. Hainan’s development mainly relies on its tourism industry, and thus its proportion of industrial energy consumption is relative low. By contrast, the proportion of industrial energy consumption in Guizhou, Qinghai and Xinjiang in 2013 was higher than the corresponding proportion in 2005, indicating a negative contribution. In such provinces as Hunan, Qinghai, and Fujian, the proportion of industrial energy consumption increased, as well as the proportion of industrial added value, indicating that industrial development

| Province     | $\Delta C_F$ | $\Delta C_M$ | $\Delta C_N$ | $\Delta C_I$ | $\Delta C_G$ | $\Delta C_{Pi}$ |
|--------------|--------------|--------------|--------------|--------------|--------------|----------------|
| Beijing      | −20.8        | 208.3        | −561.7       | −195.5       | 462.3        | 207.4          |
| Tianjin      | 5.4          | −22.3        | −64.7        | −11.2        | 141.8        | 51.0           |
| Hebei        | −2.9         | −0.7         | −135.9       | 2.0          | 221.8        | 15.5           |
| Shanxi       | −1.0         | 28.6         | −95.9        | −7.2         | 162.8        | 12.7           |
| Inner Mongolia| −7.5        | 42.9         | −142.7       | 27.2         | 175.3        | 4.8            |
| Liaoning     | −5.6         | −4.8         | −168.2       | 19.0         | 251.2        | 8.4            |
| Jilin        | 3.8          | −7.6         | −224.9       | 46.4         | 279.4        | 2.8            |
| Heilongjiang | −2.9         | 61.9         | −102.1       | −72.8        | 215.0        | 0.9            |
| Shanghai     | −10.8        | 18.4         | −98.1        | −86.4        | 83.8         | 193.0          |
| Jiangsu      | −4.5         | 30.8         | −114.4       | −30.0        | 209.5        | 8.5            |
| Zhejiang     | 3.3          | 31.9         | −138.1       | −17.5        | 199.7        | 20.7           |
| Anhui        | −2.7         | 40.0         | −177.7       | 47.4         | 195.3        | −2.3           |
| Fujian       | 0.1          | −24.2        | −84.0        | 2.8          | 195.2        | 10.1           |
| Jiangxi      | 2.7          | −5.7         | −155.6       | 38.9         | 211.4        | 8.3            |
| Shandong     | 2.4          | 2.0          | −129.5       | −34.9        | 247.8        | 12.2           |
| Henan        | −1.1         | −17.0        | −188.0       | 18.3         | 286.9        | 0.9            |
| Hubei        | 2.1          | 20.4         | −222.8       | 26.3         | 270.8        | 3.2            |
| Hunan        | 3.2          | −23.3        | −216.8       | 45.3         | 279.1        | 12.5           |
| Guangdong    | 2.7          | −9.1         | −98.0        | −11.2        | 184.5        | 31.1           |
| Guangxi      | 0.3          | 8.6          | −168.1       | 39.5         | 217.5        | 2.2            |
| Hainan       | 1.4          | 62.8         | −90.6        | −13.1        | 130.8        | 8.7            |
| Chongqing    | −11.6        | 77.1         | −235.2       | 20.4         | 237.9        | 11.5           |
| Sichuan      | −7.1         | 20.2         | −162.4       | 41.5         | 209.9        | −2.1           |
| Guizhou      | −15.9        | −52.1        | −212.4       | −14.2        | 412.6        | −18.0          |
| Yunnan       | −51.1        | −10.8        | −178.4       | −14.3        | 339.4        | 15.1           |
| Shaanxi      | 1.8          | 28.6         | −114.1       | 13.2         | 168.1        | 2.4            |
| Gansu        | −17.6        | 11.2         | −154.7       | 0.3          | 257.7        | 3.2            |
| Qinghai      | 4.9          | −50.2        | −10.1        | 20.7         | 128.5        | 6.2            |
| Ningxia      | −6.3         | 3.3          | −88.1        | −1.7         | 180.3        | 12.5           |
| Xinjiang     | 0.2          | −32.8        | 13.5         | −2.1         | 108.9        | 12.4           |
led to an increase in industrial energy consumption. The proportion of industrial added value in Tianjin, Guangdong, Guizhou, Yunnan, and Xinjiang did not increase, but industries like the manufacture of nonmetallic mineral products, smelting and pressing of ferrous metals, or the manufacture of raw chemical materials and chemical products, which are typical high-energy-consumption and low-added-value industries, developed rapidly in these regions. Accordingly, the industrial energy consumption of these five regions increased significantly as the proportion to total energy consumption.

### 4.1.3 Energy consumption per unit of industrial added value

This factor reflects the energy consumed to produce one unit of industrial added value over a given period of time. Continuous efforts are made to improve industrial energy efficiency and reduce energy consumption per unit of industrial added value. These data confirmed that this factor showed very strong negative contributions to CO₂ emission to the vast majority of provinces, and this value indicated efforts in almost all provinces for industrial energy conservation.

The contributions of energy consumption per unit of industrial added value are shown in Figure 5. For most provinces, the energy consumption per unit of industrial added value has sustained negative contribution to the emissions increment. Due to the rapid development of high-energy-consumption and low-added-value industries in Xinjiang, its energy consumption per unit of industrial added value increased in most of the years, and in turn contributed positively to the emissions increase. Heavy industries developed rapidly in Shanxi, Heilongjiang and Chongqing during 2011-2013, so the energy consumption per unit of their industrial added value increased and contributed to the increase in their provincial CO₂ emissions. The difficulty in achieving industrial technological progress had affected the declining of energy consumption per unit of industrial added value. Therefore, the negative contributions of energy consumption per unit of industrial added value to the increase in provincial carbon emissions are less during 2011-2013 than the years before.

### 4.1.4 Provincial industrial proportion

This factor reflects the proportion of industry in GDP. The industrial proportion in most provinces in eastern China showed a tendency of decline, whereas that in most middle and western provinces exhibited an increasing trend. Because Shougang Group and other industrial enterprises have been relocated, industrial proportion in Beijing was lower than before. Shanghai has implemented policies to remove ferroalloys industry in 2007 and ceased flat glass production in 2009 which leads to the decrease of industrial proportion. As one old industrial base, Heilongjiang developed its tourism.
service industry, and the proportion of tertiary industry added value of total provincial GDP increased from 33.7% in 2005 to 41.4% in 2013. Thus, its industrial proportion decreased.

As shown in Figure 6, the contributions of industrial proportion are different among provinces and specific years. This factor has negative contribution to provincial CO₂ emissions for only a few provinces during 2005-2007. For most provinces, this factor has positive contribution to the provincial emissions increase during 2005-2007 and 2009-2011 while it has negative contribution during 2009-2011 and 2011-2013.

The industrial proportion of most provinces increased as their economy developed during 2005-2007, and had positive contribution to the provincial emissions increase during 2005-2007. Due to the financial crisis in 2008, the proportion of industry in most provinces decreased, and the contributions of this factor became negative for most of the provinces. Still, there were some middle and western provinces with increasing proportion of industry which had positive contribution during this period. With the implementation of the four trillion economic stimulus plan, the industrial proportion in most provinces increased again during 2009-2011 and had positive contribution. Most provinces then started to control and reduce their industrial proportion during 2011-2013; therefore, the contributions of this factor became negative again for most of the provinces. This reflects the efforts of the economic structure reforming. In the future, the industrial proportion is expected to play an important role in reducing CO₂ emissions for more provinces.

4.1.5 | GDP per capita

This factor indicates the level of economic development in all regions. Although the speed of development in the provinces is varied, the overall pace was remarkable, so as to its contribution to total CO₂ emissions was the highest for all provinces except for Shanghai. It is predicted that GDP per capita growth will slow down, so as to CO₂ emissions growth for all provinces in China in the future.

4.1.6 | Provincial population

This factor reflects the influence of population growth and immigration to all provinces in energy consumption. For most provinces, the population growth contributed to the emissions increase. The scales of population of many large cities or provinces such as Beijing, Shanghai, Tianjin, and Guangdong, increased significantly due to migration. This increase will lead to increased energy consumption and CO₂ emission; that is, it will make a large contribution to total CO₂ emissions growth. Therefore, in the analysis of the contribution of different provinces to national CO₂ emissions.
emissions, the change in population proportion caused by migration also needs to be considered.

### 4.2 | COMPARISON OF DRIVING FORCES AMONG PROVINCES

Some forces driving provincial CO₂ emissions were similar and some are different among the provinces. GDP per capita made a significant contribution to CO₂ emissions in all provinces, and energy consumption per unit of industrial added value showed a strong negative contribution in most provinces. Other factors contributed little in most provinces but more prominent in some provinces. Energy consumption per unit of industrial added value in Qinghai and Xinjiang did not contribute negatively to CO₂ emissions. For Beijing and Shanghai, the positive contributions of the provincial population and the negative contribution of industrial proportion were also obvious. The proportion reciprocal occupied by industrial energy consumption in total energy consumption also contributed significantly to CO₂ emissions for Beijing, Chongqing, and Hainan. The contribution of proportion of industrial energy consumption and the negative contribution of industrial proportion were obvious for Heilongjiang. Unlike other provinces, CO₂ emissions per unit of energy consumption made a significant negative contribution in Yunnan.

By comparing the contributions, it is observed that Beijing, Chongqing, and Sichuan performed better than the national average in lowering provincial CO₂ emissions per unit of energy consumption, the proportion of industrial energy consumption, and energy consumption per unit of industrial added value. However, Tianjin, Fujian, Shandong, Guangdong, Qinghai, and Xinjiang performed poorly. Moreover, Henan, Hunan, Guizhou, and Yunnan performed poorly in terms of lowering the proportion of industrial energy consumption.

### 5 | CONCLUSIONS AND POLICY IMPLICATIONS

Based on the energy balance sheets, this study calculated energy consumption and CO₂ emissions in 30 provinces, municipalities, and autonomous regions in China from 2005 to 2013. CO₂ emission from net import electricity was considered as a part of provincial CO₂ emissions. The results show that total CO₂ emissions continued to rise during this period, but majority of provinces, together with the central government, have actively promoted energy conservation targets and effectively controlled the carbon intensity.

The study adopted the LMDI method for a decomposition analysis considering CO₂ emissions per unit of energy consumption, the proportion of industrial energy consumption, energy consumption per unit of industrial added value, industrial proportion, GDP per capita and population. Data at the national and provincial levels show that the increase in GDP per capita is the main factor influencing emissions increases. The driving forces are not exactly identical across the provinces and reflect provincial characteristics, except for GDP per capita. Provincial results also show that the challenge to further CO₂ emission reduction vary among provinces due to differences in the stages of development, economic structure, energy endowments, population proportion, and specific local circumstances.

To achieve the goal of reducing CO₂ emissions per unit of GDP by 40%-45% by 2020 compared with that in 2005 levels, China should continue to promote energy conservation and emissions reduction. All regions need to implement different energy conservation and emission reduction policies and measures based on varied development stages and characteristics, which can be categorized in the following:

1. **Developed regions**: Some regions such as Beijing and Shanghai are in the later stage of industrialization with advancement in modernization and tertiary industry. Therefore, these cities should properly control their energy consumption, encourage low carbon consumption, reduce the industrial energy consumption, accelerate service industries, and further enhance industrial low carbon transformation.

2. **Backward regions**: The economic aggregates and total energy consumption of Ningxia, Qinghai, Tibet, and other provinces are still in the early stage of industrialization. The levels of their economic development indicate that they still need larger development spaces. Therefore, the proportion of energy for industry and CO₂ emissions of these provinces will continue to rise. Although the environmental resources are plentiful, it is important to avoid making environmental pollution and suffering the environmental damage in exchange to economic development. Development experience from developed provinces should be thought as reference for facilitating a low carbon development pathway.

3. **Other developing regions**: Except for the above two types of regions, most provinces can be classified as developing ones, and represent the average level in China. These areas will not only witness accelerated industrial transformation, but will also develop local economy and to maintain the balance between economic development and low carbon emissions. The changing trend of total CO₂ emissions needs to be further improved as GDP per capita continues to rise. Although energy conservation is still the key factor leading to low carbon pathway, the difficulty of controlling energy consumption per unit of industrial added value will continue to increase; therefore, the economic structure needs to be adjusted continuously.
Attention should be paid not only to lower industrial proportion, but also to control the proportion of heavy industries as a means to reduce industrial energy consumption. The energy structure transition is also important to control CO₂ emissions, especially for provinces which are rich in non-fossil energy. Special attention should be paid for Tianjin, Fujian, Shandong, Guangdong, and Xinjiang to control CO₂ emissions. Henan, Hunan, Guizhou and Yunnan need to control the proportion of industrial energy consumption.

Due to the imbalanced development of all provinces across China, it is essential to take account of varied local circumstances for the implementation of energy conservation and energy intensity reduction actions, which would facilitate low carbon development. The local capacities should be fully considered in determining their emissions reduction targets and corresponding strategies for achieving both quality economic development and effective CO₂ emissions reduction, leading to sustainable development in China.

ACKNOWLEDGMENTS
Special thanks to the National Natural Science Foundation of China for its financial support under program Nos 21306099, 71690243 and 51861135102. The authors would also like to thank the editors and anonymous reviewers for their valuable comments and suggestions.

CONFLICT OF INTEREST
None declared.

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