CEEP-BIT WORKING PAPER SERIES

CEEP-BIT

Is it possible for China to reduce its total CO_2 emissions?

Huanan Li
Yi-Ming Wei

Working Paper 81
http://ceep.bit.edu.cn/english/publications/wp/index.htm

Center for Energy and Environmental Policy Research
Beijing Institute of Technology
No.5 Zhongguancun South Street, Haidian District
Beijing 100081
October 2014

This paper can be cited as: *Li H, Wei Y-M. 2014. Is it possible for China to reduce its total CO_2 emissions?. CEEP-BIT Working Paper.*

The authors gratefully acknowledge the financial support from the National Natural Science Foundation of China (Nos: 71020107026, 71401010) and the China Postdoctoral Science Foundation (No: 2014M550024). The views expressed herein are those of the authors and do not necessarily reflect the views of the Center for Energy and Environmental Policy Research.

The Center for Energy and Environmental Policy Research, Beijing Institute of Technology (CEEP-BIT), was established in 2009. CEEP-BIT conducts researches on energy economics, climate policy and environmental management to provide scientific basis for public and private decisions in strategy planning and management. CEEP-BIT serves as the platform for the international exchange in the area of energy and environmental policy.

Currently, CEEP-BIT Ranks 47, top 3% institutions in the field of Energy Economics at IDEAS（http://ideas.repec.org/top/top.ene.htm), and Ranks 52, top 3% institutions in the field of Environmental Economics at IDEAS (http://ideas.repec.org/ top/top.env.html).

Yi-Ming Wei
Director of Center for Energy and Environmental Policy Research, Beijing Institute of Technology

For more information, please contact the office:

Address:
Director of Center for Energy and Environmental Policy Research
Beijing Institute of Technology
No.5 Zhongguancun South Street
Haidian District, Beijing 100081, P.R. China

Access:
Tel: +86-10-6891-8551
Fax: +86-10-6891-8651
Email: ceeper@vip.163.com
Website: http://ceep.bit.edu.cn/english/index.htm

Is It Possible for China to Reduce its Total CO_2 Emissions?

Huanan Li [a,b,*], Yi-Ming Wei [a,b]

[a] Center for Energy and Environment Policy Research, Beijing Institute of Technology, Beijing 100081, China

[b] School of Management and Economics, Beijing Institute of Technology, Beijing 100081, China

Email address of corresponding author: huanan3721@163.com

Phone Number: +086-010-68918551

Address: Room 601, main building, 5 ZhongguancunSouth Street, Haidian District, Beijing Institute of Technology, Beijing, 100081

ABSTRACT

China's CO_2 emissions have been the focus of attention for domestic and foreign scholars. However, very few articles have analysed whether and how a reduction of China's total CO_2 emissions can be achieved. This is of great significance for meeting China's future CO_2 emissions reduction targets. Based on input-output decomposition analysis model and dynamic programming approach, this paper analyses the factors affecting China's total carbon emissions and discuss whether and how it could be possible for China to reduce its total CO_2 emissions. The results show that carbon intensity is a major driver for the reduction of China's CO_2 emissions and that the impact of industry structure on the increment of China's CO_2 emissions has changed from positive to negative in recent years. Under the premise of economic growth, carbon intensity decline and industrial structure adjustment should be coordinated. A reduction in the total amount of China's CO_2 emissions is difficult to achieve in the short term, but an effective development mode can be selected with some policy implications suggested.

Key words: CO_2 reduction; Input-Output model; SDA; dynamic programming approach; China

1. Introduction

In recent years, China's carbon dioxide (CO_2) emissions, especially its energy-related CO_2 emissions, have been the focus of attention for domestic and foreign scholars. It is not only an environmental issue but also a political and development one. China's energy consumption has increased by 2.3 times during 1990 and 2013, with an average annual growth rate of 5%. This leads to a rapid increase in China's total CO_2 emissions. The Chinese government made a clear commitment at the Copenhagen conference to decrease its CO_2 emissions per unit GDP by 40-45% compared with emissions level in 2005 by 2020. Especially during the recent Beijing APEC, China and the US issued the "China-US Joint Statement on Climate Change", in which China plans to control its CO_2 emissions peak around 2030, and as early as possible. The Chinese government has indeed undertaken much work to promote China's CO_2 reduction, achieving positive results. From 2000 to 2013, China's average annual rate of decrease in CO_2 intensity was 2.46%, and the total decrease was by 21.06%, whereas China's GDP increased by 190.64%, with an average annual growth rate of 9.95%. Despite the positive results, China's carbon emissions have still increased rapidly in recent years. China's total CO_2 emissions grew by 129.43% from 2000 to 2013, with an average annual growth rate of 7.25%. If the commitment made by the Chinese government at the Copenhagen Climate Conference can be achieved and we assume that China's average annual growth rate of GDP in its 12th and 13th five-year plans is 7% and 6%, respectively, the average annual growth rate of China's total CO_2 emissions is 3.38% in the case of CO_2 emissions per unit GDP being decreased by 45% and 4.15% when the per unit GDP decreases by 40%. China's CO_2 emissions were nearly 85 million tonnes in 2013, accounting for approximately 27% of total global emissions, which is an enormous amount. However, China is still a developing country, and the rapid increase in carbon emissions is only a consequence of its development over the last ten years. Due to the rapid development of its economy, China inevitably needs to rely on a large amount of energy consumption, similar to other developed countries that have gone through this stage. Therefore, the delineation of responsibilities on the total amount reduction of China's carbon emissions is still premature. However, from a research perspective, the delineation of China's future total CO_2 reduction targets is of great significance and is the intention of this study.

There have been many researches on issues of CO_2 emissions on international，such as Sun (1999), Hsu and Chen (2004), Savabi and Stockle (2001), Gielen and Moriguchi (2002), Christodoulakis (2000) [1-5]. Joao Gomes et al., described the study that led to the development of a CO_2 emissions matrix for the Oeiras municipality [6]. R.A.F. Tomas et al., made an assessment of the impact of the enforcement of the European CO_2 emissions trading scheme on the Portuguese chemical industry, based on cost structure, CO_2 emissions, electricity consumption and allocated allowances data [7]. However, the issue of total CO_2 emissions reduction studied on most other countries is rarely involved, and this may be because the proportions of their total CO_2 emissions on global carbon emissions are relatively small. For China's carbon emissions, related researches are very widely, such as factors impacting carbon emission [8-12], import and export trade [13-15], carbon footprints [16-19], and other related issues [20-22]. Chengxu Xu studied the relationship between China's carbon emissions and GDP using a fitting model and made carbon emissions projections for reasonable policy proposals [23].Zhang found that China’s carbon emissions driven by capital formation are greater than consumption [24]. Using the CGE model based on the 2002 IO table, Lu analysed the impact on the economy and CO_2 emissions with increasing investment in the energy sectors. According to the results, carbon emissions and GDP will increase by 11.10% and 8.92% respectively when there is a 60% increase in energy investment [25]. Sun accounted for Chinese carbon emissions over the years based on the IPCC listing. The results found that the manufacturing, electrical and thermal industries and agriculture accounted for over 80% of the total emissions footprint [26]. Shenggang Ren et al., analysed the scale and structure of embodied carbon emissions of China's industry sectors during 2001–2011 and established the relationship among energy intensity, trade comparative advantage, per capital output, CO_2 emission intensity, environmental regulation, foreign direct investment (FDI), trade openness and technology [27]. At the sector level, several major emission-intensive sectors, including the electricity sector, were chosen to investigate the scenarios of China's CO_2 mitigation in 2020 [28]. Wenjia Cai et al., employed three scenarios based on the "long-range energy alternative planning system" (LEAP) model to simulate the different development paths of this sector for assessing the CO_2 emissions reduction potential of China's electricity sector [29]. Thus far, there have been rich results from different perspectives on the issues surrounding China's carbon emissions. However, as the largest CO_2 emission country whose CO_2 emissions accounting for approximately 27% of total global emissions in 2013, few analyses have focused on the problem from the perspective of reductions of total CO_2 emissions in China.

From the perspective of research methods on energy and energy-related CO_2 emissions, input–output model (IOM) is a useful tool firstly developed by Leontief [30], which has been widely used now [31-34]. Murthy et al., analysed CO_2 emissions from energy consumption for different sectors of India [35]; Hongtao Liu et al., evaluate the energy embodied in goods produced in China during 1992–2005 and use input–output structural decomposition analysis to identify five key factors causing the changes of energy embodied in exports [36]. Pachauri and Spreng analysed direct and indirect energy requirements of households for the years1983–1984, 1989–1990 and 1993–1994 [37]. In recent years, built on the input–output model, structural decomposition analysis (SDA) has been developed to analyse the key factors underlying the changes in CO_2 emissions. After identifying the factors affecting on CO_2 emissions in Japanese industries during 1985–1995, Nobuko found that changes in both production technology and environment contributed to a decrease in CO_2 emissions [38]. A structural decomposition analysis (SDA) is employed to analyse the driving factors for changes in CO_2 emissions embodied in China's exports to the US during 2002-2007 by Huibin Du [39]. Cheng and Lin studied the main factors that affected CO_2 emission changes in Taiwan's petrochemical industries during 1984-1994 and gave the relative contribution of each factor to industrial CO_2 emission changes [40]. However, structural decomposition model based on IOM can only be used for the research of past trends, while the future changes can't be analysed. Programming approach is a good choice to overcome this shortcoming. For example, using programming analysis, Manne and Richels established a Global 2100 model to evaluate the costs and benefits of controlling CO_2 emissions for the US [41]. Tser-yieth Chen used a multi-objective programming approach and a Leontief inter-industry model to investigate the impact of mitigating CO_2 emissions on Taiwan's economy [42]. Fells and Woolhouse provided an optimization model to estimate the impact of mitigating CO_2 emissions on economic growth in the UK [43]. In 1993, Rose presented a non-linear programming model to simulate the net welfare changes of various strategies for the mitigation of CO_2 emissions for eight countries with Steven [44], then he provided a linear-programming model to evaluate reduction in GDP resulting from five proposed CO_2 emissions mitigation programs in China in 1995 [45]. In this study, SDA model based on IOM and dynamic programming approach are combined to analyse China's CO_2 emissions.

In summary, different from other researches, this article tries to explore the problem, namely the status of China's total CO_2 emissions and how to achieve total reduction. Based on combined method of input-output decomposition model and dynamic programming approach, this paper describes the factors affecting China's total carbon emissions firstly, and then discusses the possible way for China to reduce its total CO_2 emissions, to get more policy implications on China's CO_2 emissions reduction.

2. Methodology

2.1 Research Framework

First, the incremental contribution of China's total CO_2 emissions is decomposed based on the input-output model to analyse the impact of three factors, namely CO_2 intensity, industrial structure and final demand, on China's carbon emissions and search for trends. Then, using the results of the structural decomposition model, a dynamic single-objective optimisation model is established to analyse the development path for China to achieve its total CO_2 emissions reduction. The research framework of this paper is shown in Fig. 1.

2.2 Decomposition and Optimisation method

The input–output model (IOM) was first proposed by Leontief et al. [46] for analysing energy consumption predictions and energy-related policies in the United States, where, in addition to being a data source, important models have been used to analyse the linkage of production and consumption at the sector level [47]. Thus far, IOM has been widely applied to fields such as energy, environment, embodied emissions and international trading [48-54]. The basic function can be described as follows:

$$X = AX + Y = (I - A)^{-1} Y = BY \tag{1}$$

Where X denotes column vector of total output; Y is the column vector of final demand; A represents technology coefficient matrix, whose element a_{ij} indicate production of sector i required by the sector j; AX denotes the intermediate input vector; I is the identity matrix; and $(I-A)^{-1}$ is Leontief's Inverse Matrix, named as *B*.

The direct CO_2 emission coefficient is calculated as the ratio of direct CO_2 emissions to total outputs. For sector *i*, if the CO_2 emissions of *i* is $em_{i,CO2}$, the direct CO_2 emissions coefficient e_i can be computed as follows:

$$e_i = \frac{em_{i,co_2}}{X_i} \tag{2}$$

Thus, the total CO_2 emissions (denoted by *Q*) can be estimated as follows:

$$Q = \sum_i e_i x_i = eX = eBY \tag{3}$$

According to SAD method based on IOM, incremental CO_2 emissions during two periods can be considered to be caused by changes in emissions factor "e", industrial structure "B" and final demand "Y". Then, we can obtain the following equation:

$$\Delta Q = Q(\Delta e) + Q(\Delta B) + Q(\Delta Y) \tag{4}$$

Where ΔQ means the increased amount of CO_2 emissions between two periods and $Q(\Delta e)$, $Q(\Delta B)$ and $Q(\Delta Y)$ denote the increased CO_2 emissions caused by changes in *e, B,* and *Y*. According to the SAD method proposed by Jinghua Li [55], the following equations can be obtained:

$$\begin{aligned} Q(\Delta e) &= \frac{1}{3}(\Delta e)B_0Y_0 + \frac{1}{6}(\Delta e)B_0Y_1 + \frac{1}{6}(\Delta e)B_1Y_0 + \frac{1}{3}(\Delta e)B_1Y_1 \\ Q(\Delta B) &= \frac{1}{3}e_0(\Delta B)Y_0 + \frac{1}{6}e_1(\Delta B)Y_0 + \frac{1}{6}e_0(\Delta B)Y_1 + \frac{1}{3}e_1(\Delta B)Y_1 \\ Q(\Delta Y) &= \frac{1}{3}e_0B_0(\Delta Y) + \frac{1}{6}e_1B_0(\Delta Y) + \frac{1}{6}e_0B_1(\Delta Y)_1 + \frac{1}{3}e_1B_1(\Delta Y) \end{aligned} \tag{5}$$

Where 0 and 1 indicate the base period and target period respectively.

For further studying the minimisation of the increment of total CO_2 emissions, the following dynamic objective planning model can be obtained:

$$Min\sum_{i=1}^{t}\Delta Q_i$$

$$\text{s.t. } e, B, Y \in \Omega \tag{6}$$

Where ΔQ_i means the increment of total CO_2 emissions between periods *i* and *i*-1, and Ω is the constraint space. Thus, equation 6 can be described as follows:

$$\begin{aligned} Min\sum_{i=1}^{t}\Delta Q_i &= \sum_{i=1}^{t}(\Delta e_i + \Delta B_i + \Delta Y_i) \\ &= \sum_{i=1}^{t}\frac{1}{2B\sigma}[(e_i - e_{i-1})(Y_i + Y_{i-1}) + (e_i + e_{i-1})(Y_i - Y_{i-1})] \end{aligned} \tag{7}$$

$$\begin{aligned} \text{s.t. } \quad & Y_i = (1 + s\%)Y_{i-1} \\ & y_{i,j} \geq \gamma y_{i-1,j} \\ & \omega * e_{i-1,j} \leq e_{i,j} \leq e_{i-1,j} \\ & e = \Phi Y \end{aligned}$$

Where j is the sub-sector; σ is constant after formula manipulation; s denotes the rate of increase of the final demand Y; γ means the lower limit of growth of the final demand y of subsector j; ω is the lower limit of the decrease of e in subsector j; and φ is the function of e and Y.

2.3 Data Sources

The data used in this paper are primarily from the China Energy Statistical Yearbook [56], China Statistical Yearbook [57], China's 17 Sector Input-Output Tables (2002/2005/2007/2010), surveys and the authors' calculations. The total output at constant prices was not considered in this paper due to the absence of data. The abbreviations for the subsectors in this paper are expressed in table 1.

3. Results and discussion

3.1 Input-Output analysis of China's CO_2 emissions factors

Based on the IOM mentioned above, increments of China's CO_2 emissions during three periods (2002-2005, 2005-2007 and 2007-2010) are decomposed. The results are as follows.

3.1.1 Different factors have different impacts on the increment of China's CO_2 emissions

The impacts of three factors, i.e., carbon intensity "e", industrial structure "B", and economic growth "Y", on China's CO_2 emissions during these three periods are shown in Fig. 2. It's obvious from the figure that the impacts of the three factors are quite different, and all of them have some variable trends during these years. Specifically, carbon intensity has a significant negative impact on the increment of China's CO_2 emissions, whereas change in industry structure and economic growth have positive impacts. In descending order of importance, economic growth, carbon intensity and change in industry structure contribute to China's CO_2 emissions. In general, the total impact of these three factors is positive, which is because the contribution from economic growth is huge. We also find that the positive impact of change in industry structure on the increment of China's CO_2 emissions is decreasing, but that in economic growth is increasing. This is the mixed result of economic growth and the adjustment in industry structure. This shows that in recent years, China's industrial structure adjustment has played a positive role for its carbon reduction, however, the economic growth has weakened the influence to some extent.

To be specific, the direct and indirect impacts of each factor on China's CO_2 emissions are shown from Figs. 3 to 5. Fig. 3 gives a clear description of the impact of factor "e". Factor "e" has a negative impact on the increment of China's CO_2 emissions, in other words, it reduced China's CO_2 emissions. The proportions of direct decrements of China's CO_2 emissions over the total decrements in all of the three periods generated by factor "e" are less than 40 percent, while the proportion increases from 32.38% to 39.86% from 2002-2005 to 2007-2010. The synergistic effect between "e", "B", and "Y" makes a major contribution to the growth of China's CO_2 emissions. Noteworthy, the proportion of the synergistic effect decreases from 67.62% to 60.14% from 2002-2005 to 2007-2010. That means the contribution of the indirect impact of factor "e", namely the synergistic effect between "e", "B", and "Y", to China's CO_2 emissions reduction has decreased noticeably during the past three periods.

In Fig. 4, the direct and indirect impacts of factor "B" on China's CO_2 emissions are presented. Obviously, that factor "B" has a positive impact on the increment of China's CO_2 emissions during the periods of 2002-2005 and 2005-2007, whereas its impact is negative from 2007to 2010. This result proves that the adjustment of China's industrial structure has decreased China's total CO_2 emissions gradually. During the first two periods, the increments of China's CO_2 emissions generated by factor "B" are equally from its direct and indirect impact, however, when factor "B" has a negative impact on the increment of China's CO_2 emissions, its direct impact is a major contribution, accounting for 65.51% of the total impact during the period 2007-2010.

Fig. 5 gives a clear description on the impact of factor "Y". The direct and indirect impact of factor "Y" is opposite, namely, one is positive and another is negative, while the total impact of factor "Y" on the increment of China's CO_2 emissions is positive. In recent years, the rapid growth of China's economy has greatly increased China's total CO_2 emissions. The increments of China's CO_2 emissions in these three periods directly generated by factor "Y" are more than 98 percent, while its indirect impact, namely the synergistic effect between "Y" and "e", "B", reduced China's CO_2 emissions with a small contribution. Fortunately, the synergistic effect between "Y" and "e", "B" is increasing, which is a small but important amount. Considering China's current national conditions, the rapid development of China's economy will inevitably lead to an increase in its CO_2 emissions. With the adjustment of industry structure and improved energy efficiency, a reduction in China's total CO_2 emissions is possible, as reflected in Fig. 5.

3.1.2 Sector analysis on China's CO_2 emissions

From the overall analysis, the effects of these three factors on the China's CO_2 emissions during different periods have different characteristics that are non-specific to the industry sector. Thus, the effects of different sectors and different factors on China's CO_2 emissions from the industry perspective are analysed, as shown in Figs. 6-8.

Fig. 6 gives the sector analysis of the effect of factor "e" on China's CO_2 emissions. According to the previous results in Fig.3, factor "e" has a negative impact on the increase in China's CO_2 emissions, that is, conducive for China's CO_2 reduction. For consistency, in this figure, the positive contributor means the sector with a decrease in CO_2 intensity decreased China's CO_2 emissions, whereas a negative contributor refers to a sector with a decrease in CO_2 intensity increased China's CO_2 emissions. Obviously, most sectors have a positive impact, which means that decreasing carbon intensity of these sectors has decreased China's CO_2 emissions. The main positive contributors are sectors such as CG, CI, MN, MP, and TS, among which MP is biggest, accounting for 36.97% of the total CO_2 reductions caused by factor “e” from2005 to 2007. In addition, values of some negative contributor such as sector TS and WR are relatively small compared with that of most positive contributors. From the perspective of changing trend, the impact value of most positive contributors have been increasing during recent years, and the impact value of negative contributors also converted to positive gradually. All of these results prove that decreasing carbon intensity at the sector level greatly slowed the increase of China’s CO_2 emissions.

Fig. 7 gives the sector analysis of the effect of factor “B” on China’s CO_2 emissions. According to the previous results in Fig.4, it is noteworthy that factor “B” has a positive impact during the periods 2002-2005 and 2005-2007 but a negative impact from 2007-2010. Thus, in the first two periods, the positive contributor denotes the sector that the change of factor “B” of it increases China’s CO_2 emissions, whereas the negative contributor refers to the sector that decreases China’s CO_2 emissions. In contrast, in the last period, the positive contributor means the sector that the change of factor “B” of it decreases China’s CO_2 emissions, and the negative contributor refers to the sector that increases China’s CO_2 emissions, as shown in Fig. 7. Obviously, the changes of factor “B” of most sectors have a positive impact on China’s CO_2 emissions in the first two periods, which means that the adjustment of their industry structure in these years increases the increment of China’s CO_2 emissions. The main positive contributors are sectors such as PH, CG, CI and MP, and the main negative contributors are TS. The biggest contributor is MP, which accounts for 74.08% of the total increment of China’s CO_2 emission caused by factor “B” during 2005 and 2007. During the period from 2007 to 2010, the changes of factor “B” of sectors such as M, MN and TS, have a positive impact on China’s CO_2 reduction, while the changes of factor “B” of sectors such as PH, CG, CI and MP, still increased China’s CO_2 emissions. This shows that these four sectors have always increased in China's CO_2 emissions, therefore, CO_2 reduction of these sectors would contribute more to China's total carbon emissions reduction. It’s noteworthy that the impact value of most positive contributors have been decreasing during recent years, and converted to negative gradually. From the above analysis, industrial restructuring in recent years gradually plays a role in reducing China's CO_2 emissions.

Fig. 8 gives the sector analysis of the impact of factor "Y" on China's CO_2 emissions. All of the sectors have a positive contribution, signifying that the economic growth of all sectors increases China's CO_2 emissions over all three periods. The main positive contributors are sectors such as CG, CI, MN, MP, and TS, which are all energy-intensive sectors that rely on energy usage. The biggest contributor is MP, which accounts for 34.01% of the total CO_2 emissions caused by factor "Y" during the period of 2005 and2007. It can be also found that the positive contributions of most sectors have gradually decreased in recent years. That is because the industry structure adjustments and carbon intensity improved in these sectors, which caused the synergistic effect. Thus, a further restructuring of industry and reducing carbon intensity and is necessary with the rapid increase in economy in China.

Based on the above calculation, the increment of China's CO_2 emissions caused by GDP growth with that caused by the decrease in carbon intensity are compared, as shown in Fig. 9. In this figure, the histogram notes the percentage of CO_2 intensity that should be decreased for offsetting the increase in China's CO_2 emissions caused by 1% GDP growth without changes in industry structure. Thus, the smallest percentage is 0.55 during 2002-2005, and the biggest is 1.15 during 2007-2010. The average percentage is 0.74 during 2002-2010. It is important to note that the percentage has increased during these years, signifying that the CO_2 increase caused by the rapid growth of the energy-intensive economy is becoming more and more difficult to be eliminated. This trend should capture the attention of policy makers.

3.2 Optimisation analysis on the increment of China's CO_2 emissions

What mode of development for China's economy will make the minimum increase in China's CO_2

emissions? This is a question studied by many scholars. Based on scenario analysis and a simple dynamic optimisation approach, an analysis from the perspective of sectors is performed. In this article, every two years are set as a planning period, assuming that the average annual growth rate of GDP is 7.5 and 6.5 percent respectively, during the periods of 2010-2015 and 2015-2020, and “B” in the input-output table of 2010 remains unchanged. The results are as follows.

3.2.1 Reduction of China’s total CO_2 emissions is difficult to achieve in the short term

Fig. 10 gives the historical trends of CO_2 intensity and the GDP of sub-sectors. Based on the statistical data, the sectors with a larger change in CO_2 intensity are M, CI, MN (decreased by 60.95% from 2002 to 2010), MP and TS, whereas the sectors with a larger change in GDP growth are A, MN (increased by 286% from 2002 to 2010), WR and OS. It is worth noting that over the past few years, most of the departments with larger changes in CO_2 intensity are energy-intensive heavy industries, whereas those with a larger GDP growth rate are the service and high-tech industries. The results are consistent with China’s CO_2 reduction and industrial structural adjustment policies, which have been upheld in the last decade.

After the calculation, optimisation results for increments of China’s CO_2 emissions are obtained, as shown in Fig. 11. Based on the given scenario and the input-output data from2010, the optimal results show that the smallest increment of CO_2 emissions from 2010 to 2020 could achieve 1.877 billion tonnes according to the optimisation results for China. From the perspective of annual increments, the optimal results are decreasing, indicating that the potential of CO_2 emissions reduction is gradually reduced as CO_2 reduction policies are implemented.

Fig. 12 gives the optimisation results of CO_2 intensity and the GDP of sub-sectors. The sectors with a larger changes in CO_2 intensity are M, CG, CI, MN, MP and TS, whereas the sectors with a larger changes in GDP growth are MM, TS, RE and OS. The results are similar to the analysis in Fig. 9, which means that

China's CO_2 reduction and industrial structural adjustment policies which have been upheld over the last decade should be continued, particularly in the energy-intensive heavy industries.

Specifically, the sectors with proportions of industrial structure increased are RE, TS, MP, CI and OM, and the sectors with the proportion of industrial structure decreased are WR, MF and C, as shown in Fig. 13. From the optimisation results, adjusting the industrial structure of these departments will play a positive role in promoting reductions of China's CO_2 emissions in the future.

3.2.2 Still a long way from reduction of China's total CO_2 emissions

According to Equation 7, if the increase in China's CO_2 emission is less than zero, the following equation can be obtained:

$$\kappa \geq \frac{r}{r+1} \tag{8}$$

where k denotes the expected deceleration of CO_2 intensity and r is the growth rate of GDP. The results are shown in Fig. 14. It's obvious that the expected decelerations of CO_2 intensity in all periods are bigger than 12%, even reaching 16.07% during 2005-2007, whereas the actual average annual decrease rates of CO_2 intensity in all periods are relatively small. This result shows that although the carbon intensity has been significantly improved in recent years, there is still a long way to go to achieve the goal of reducing the total amount of CO_2 emissions. Fortunately, the gap is decreasing, as shown in this figure. Thus, continuing to reduce CO_2 intensity for the reduction in total CO_2 emissions is still essential in the long term.

4. Conclusions and Policy Implications

After describing the factors that influence China's total carbon emissions by using the SDA model built on IOM, dynamic programming approach is applied to discuss the possible mode of reduction for China. The specific conclusions derived from the present study can be listed as follows:

(1) Carbon intensity is a major driver for the decrease in China's CO_2 emissions, whereas the increase

of final demand significantly increased the increment of China’s total CO_2 emissions. In recent years, the impact of changes in industry structure changes from positive to negative, meaning that changes in industry structure have reduced China’s total CO_2 emissions gradually;

(2) From 2002 to 2010, the average CO_2 intensity should reduce by 0.74 percentage points for offsetting the increment of China’s CO_2 emissions caused by the 1% increase in final demand growth;

(3) Under the premise of economic growth, the decline in carbon intensity and the adjustment of industry structure should be coordinated to minimise the increment of carbon emissions, and special attention should be paid to mining, the coking, gas and oil processing industries, the chemical industry, the non-metallic mineral products industry and other industries;

(4) With the certain growth of the economy, a reduction in the total amount of China’s CO_2 emissions is difficult to achieve in the short term but may be achieved in the long run.

China's CO_2 emissions, which is not just an environmental issue but also a political and development one, have been the focus of attention by domestic and foreign scholars in recent year. Due to the rapid development of its economy, China inevitably needs to rely on a large amount of energy consumption, similar to other developed countries that have gone through this stage. As a developing country, the delineation of responsibilities regarding the reduction of total CO_2 emissions for China is still premature. However, from a research perspective, the delineation of possible way for China to achieve its target on total CO_2 reduction is highly significant.

From the results of this paper, following policy recommendations are given. First, China’s government should continue to reduce the CO_2 intensity of sub-sectors such as the coke, gas and oil processing industry, the chemical industry, the non-metallic mineral products industry, metal product manufacturing, transportation and warehousing, information transmission, computer services and the software industry. Second, more attention should be paid to the rebound effects on China’s CO_2 emissions of some sectors such as construction, wholesale and retail trade, the accommodation and catering industry, real estate, renting and business services. Third, Chinese government should continue to promote the optimisation of industrial structure, paying attention to the sectors for which structural change decreases China's CO_2 increments, such as agriculture, forestry, animal husbandry and fisheries, mining industry, non-metallic mineral products industry, transportation and warehousing, postal services, information transmission, computer services and software industry. Finally, China should reasonably increase the proportion of the total economy of sectors such as real estate, renting and business services, postal transportation and warehousing, information transmission, computer services and software industry, metal product manufacturing, chemical industry, and other manufacturing industries.

5. Acknowledgement

The authors gratefully acknowledge the financial support from the National Natural Science Foundation of China (Nos: 71020107026, 71401010) and the China Postdoctoral Science Foundation (No: 2014M550024).

References

[1] Sun, J.W.. The nature of the CO_2 emissions Kuznets curve. Energy Policy1999; 27:691-694.

[2] Hsu, C.C., Chen, C.Y.. Investigating strategies to reduce CO_2 emissions from the power sector of Taiwan. International Journal of Electrical Power& Energy Systems 2004; 26:487-492.

[3] Savabi, M.R., Stockle, C.O.. Modelling the possible impact of increased CO_2 and temperature on soil water balance, crop yield and soil erosion. Environmental Modelling & Software 2001; 16:631-640.

[4] Gielen, D., Moriguchi, Y.. Modelling CO_2 policies for the Japanese iron and steel industry. Environmental Modelling & Software 2002; 17:481-495.

[5] Christodoulakis, N.M., Kalyvitis, S.C., Lalas, D.P., Pesmajoglou, S.. Forecasting energy consumption

and energy related CO_2 emissions in Greece: an evaluation of the consequences of the Community Support Framework II and natural gas penetration. Energy Economics 2000; 22:395-422.

[6] Joa˜o Gomes, Joana Nascimento, Helena Rodrigues. Estimating local greenhouse gas emissions-A case study on a Portuguese municipality. International journal of greenhouse gas control 2008; 2: 130-135.

[7] R.A.F.Tomas, F.RamoaRibeiro, V.M.S.Santos, J.F.P.Gomes, J.C.M.Bordado. Assessment of the impact of the European CO_2 emissions trading scheme on the Portuguese chemical industry. Energy Policy 2010; 38:626-632.

[8] Claudia Sheinbaum, Belizza J. Ruíz, Leticia Ozawa. Energy consumption and related CO_2 emissions in five Latin American countries: Changes from 1990 to 2006 and perspectives. Energy 2011; 36:3629-38.

[9] Shoufu Lin, Dingtao Zhao, Dora Marinova. Analysis of the environmental impact of China based on STIRPAT model. Environmental Impact Assessment Review 2009; 29:341-7.

[10] L Wu, SKaneko,S Matsuoka. Driving forces behind the stagnancy of China's energy-related CO_2 emissions from 1996 to 1999: the relative importance of structural changes, intensity change and scale change. Energy Policy 2005; 33:319-35.

[11] Huanan Li, Hailin Mu, Ming Zhang, Nan Li. Analysis on influence factors of China's CO_2 emissions based on Path-STIRPAT model. Energy Policy 2011; 39:6906-6911.

[12] Huanan Li, Hailin Mu, Ming Zhang. Analysis of regional difference on impact factors of China's energy –related CO_2 emission. Energy 2012; 39(1):319-326.

[13] Guan,D., Peters, G.P.,Weber, C.L., Hubacek,K.. Journey to World Top Emitter: An Analysis of the Driving Forces of China's Recent CO_2 Emissions Surge. Geophysical Research Letters 2009; 36, L04709, http://dx.doi.org/10.1029/ 2008GL036540.

[14] Weber, C.L., Peters,G.P., Guan,D., Hubacek,K., 2008.The contribution of Chinese exports to climate change. Energy Policy2008; 36(9):3572-77.

[15] Shao, S., Yang,L.-L., Yu,M.-B., Yu,M.-L.. Estimation, characteristics, and determinants of energy-related industrial CO_2 emissions in Shanghai (China), 1994–2009. Energy Policy 2011; 39, 6476-94.

[16] P.Yuan, S.Cheng. Determinants of carbon emissions growth in China: a structural decomposition analysis. Energy Procedia 2011; 5: 169-175.

[17] H.B.Zhang, Y.Qi.A structure decomposition analysis of China's production-source CO_2 emission: 1992–2002. Environmental and Resource Economics 2011; 49(1): 65-77.

[18] X.Tian, M.Chang, H.Tanikawa. Structural decomposition analysis of the carbonization process in Beijing: a regional explanation of rapid increasing carbon dioxide emission in China. Energy Policy 2013; 53: 279-286.

[19] Y.F.Chang, C.Lewis, S.J.Lin. Comprehensive evaluation of industrial CO_2 emission (1989-2004) in Taiwan by input-output structural decomposition. Energy Policy 2008; 36(7): 2471-80

[20] Shiwei Yu, Yi-Ming Wei, Ke Wang. Provincial allocation of carbon emission reduction targets in China: An approach based on improved fuzzy cluster and Shapley value decomposition. Energy Policy 2014; 66:630-644.

[21] Ke Wang, Xian Zhang, Yi-Ming Wei, Shiwei Yu. Regional allocation of CO_2 emissions allowance over provinces in China by 2020. Energy Policy 2013; 54:214-229.

[22] Wei YM, Wang L, Liao H, Wang K, Murty T, Yan J.. Responsibility accounting in carbon allocation: A global perspective. Applied Energy 2014; 130:122-133.

[23] Chengxu Xu. China's carbon emission prediction and its relationship with GDP. Economic review 2010;10.

[24] B. Zhang, G.Q. Chen. Methane emissions by Chinese economy: Inventory and embodiment analysis. Energy Policy 2010; 38(8): 4304-4316.

[25] C. Lu, X. Zhang, J. He. A CGE analysis to study the impacts of energy investment on economic growth and carbon dioxide emission: a case of Shanxi Province in western China. Energy 2010; 35(11): 4319-4327.

[26] J.W. Sun, Z.G. Chen, R.Q. Zhao, X.J. Huang, L. Lai. Research on carbon emission footprint of China based on input-output model. China Population, Resources and Environment 2010; 20(5):28-34.

[27] Shenggang Ren, Baolong Yuan, Xie M, Xiaohong Chen. The impact of international trade on China's industrial carbon emissions since its entry into WTO. Energy Policy 2014; 69:624-634.

[28] Zhou, D., Dai et al.. China's Sustainable Energy Scenarios in 2020. Beijing: China Environmental Science Press; 2003.

[29] Wenjia Cai, Can Wang, Ke Wang, Ying Zhang, and Jining Chen. Scenario analysis on CO_2 emissions reduction potential in China's electricity sector. Energy Policy 2007; 35: 6445-56.

[30] Leontief, W.. Environmental repercussions and the economic structure: an input–output approach. The Review of Economics and Statistics 1970; 52(3): 262-271.

[31] Hawdon, D., Pearson, P.. Input–output simulations of energy, environment, economy interactions in the UK. Energy Economics 1995; 17 (1):73-86.

[32] Schaeffer, R., LealdeSa, A.. The embodiment of carbon associated with Brazilian imports and exports. Energy Conversion and Management 1996; 37 (6-8):955-960.

[33] Kondo, Y., Moriguchi, Y.. CO_2 emissions in Japan: Influences of imports and exports. Applied Energy 1998; 59(2–3):163-174.

[34] Machado, Giovani, Schaeffer, Roberto, Worrell, Ernst. Energy and carbon embodied in the international trade of Brazil: an input–output approach. Ecological Economics 2001; 39 (3):409-424.

[35] Murthy, N.S., Panda, M., Parikh, J.. Economic development, poverty reduction and carbon emissions in India. Energy Economics 1997; 19 (3):327-354.

[36] Hongtao Liu, Youmin Xi , Ju'e Guo , Xia Li. Energy embodied in the international trade of China: An energy input–output analysis. Energy Policy 2010; 38: 3957-64.

[37] Pachauri, S., Spreng, D.. Direct and indirect energy requirements of households in India. Energy Policy 2002; 30 (6): 511-523.

[38] Nobuko, Y.. An analysis of CO_2 emissions of Japanese industries during the period between 1985 and 1995. Energy Policy 2004; 32(5):595-610.

[39] Huibin Du, Jianghong Guo, Guozhu Mao. CO_2 emissions embodied in China–US trade: Input–output analysis based on the emergy/dollar ratio. Energy Policy 2011; 39:5980-87.

[40] Cheng, Y.F., Lin, S.J.. Structural decomposition of CO_2 emissions from Taiwan's petrochemical industries. Energy Policy 2001; 29(3):237-244.

[41] Manne, A.S., Richels, R.G.. Global CO_2 emissions reduction: the impact of rising energy costs. Energy Journal 1991; 12(1):87-107.

[42] Tser-yieth Chen. The impact of mitigating CO_2 emissions on Taiwan's economy. Energy Economics 2001; 23:141-151.

[43] Fells, L., Woolhouse, L.. A response to the UK National Program for CO_2 emissions. Energy Policy 1994; 22 (8):666-684.

[44] Rose, A., Steven, B.. The efficiency and equity of marketable permits for CO_2 emissions. Resource Energy Econ 1993; 15:117-146.

[45] Rose, A.. Global Warming Policy, Energy, and the Chinese Economy. Pennsylvania: Pennsylvania University Press; 1995.

[46] Leontief, W., Quantitative. Input and output relations in the economic system of the United States. Review of Economic Statistics 1936; 18(3):105-125.

[47] Fangyi Li, Zhouying Song, Weidong Liu. China's energy consumption under the global economic

crisis: Decomposition and sectoral analysis. Energy Policy 2014; 64:193-202.

[48] Chen, Z.M., Chen, G.Q.. An overview of energy consumption of the globalized world economy. Energy Policy 2011; 39(10):5920-28.

[49] Alcántara, V., Padilla, E.. “Key” sectors in final energy consumption: an input–output application to the Spanish case. Energy Policy 2003; 31(15):1673-78.

[50] Oliveira, C., Antunes, C.H., 2001. Amulti-objective multi-sectoral economy-energy- environment model: application to Portugal. Energy 2001; 36 (5):2856-66.

[51] Liu, Z., Geng,Y., Lindner,S., Zhao,H., Fujiata,T., Guan,D.. Embodied energy use in China’s industrial sectors. Energy Policy 2012; 49:751-758.

[52] Liang, S., Wang, C., Zhang, T.. An improved input–output model for energy analysis: A case study of Suzhou. Ecological Economics 2010; 69(9):1805-13.

[53] Turner, K., Lenzen, M., Wiedmann, T., Barrett, J.. Examining the global environmental impact of regional consumption activities - part 2: review of input-output models for the assessment of environmental impacts embodied in trade. Ecological Economics 2007; 61(1):15-26.

[54] Dong, Y.L., Ishikawa, M., Liu, X., Wang, C.. An analysis of the driving forces of CO_2 emissions embodied in Japan-China trade. Energy Policy 2010; 38(11):6784-92.

[55] Jinghua Li. Weighted average decomposition SDA model and its application in China's economic development in the third industrial. Systems Engineering 2004; 9: 69-73.

[56] National Bureau of Statistics of China. China Energy Statistical Yearbook (2003/2006/2008/2011). Beijing: China Statistics Press; 2003/2006/2008/2011.

[57] National Bureau of Statistics of China. China Statistical Yearbook (2003/2006/2008/2011). Beijing: China Statistics Press; 2003/2006/2008/2011.

Table 1. Abbreviations for the subsectors in this paper

Symbol	Sector
A	Agriculture, Forestry, Animal Husbandry & Fishery
M	Mining
MF	Manufacture of Foods, Beverage & Tobacco
MT	Manufacture of Textile, Clothing Apparel & Leather Products
OM	Other Manufacture Production and Supply of Electric
PH	Power, Heat Power and Water
CG	Coking, Gas and Processing of Petroleum
CI	Chemical Industry
MN	Manufacture of Nonmetallic Mineral Products
MP	Manufacture and Processing of Metals and Metal Products
MM	Manufacture of Machinery and Equipment
C	Construction
TS	Transport, Storage, Post, Information Transmission, Computer Services & Software
WR	Wholesale and Retail Trades, Hotels and Catering Services
RE	Real Estate, Leasing and Business Services
FI	Financial Intermediation
OS	Other Services

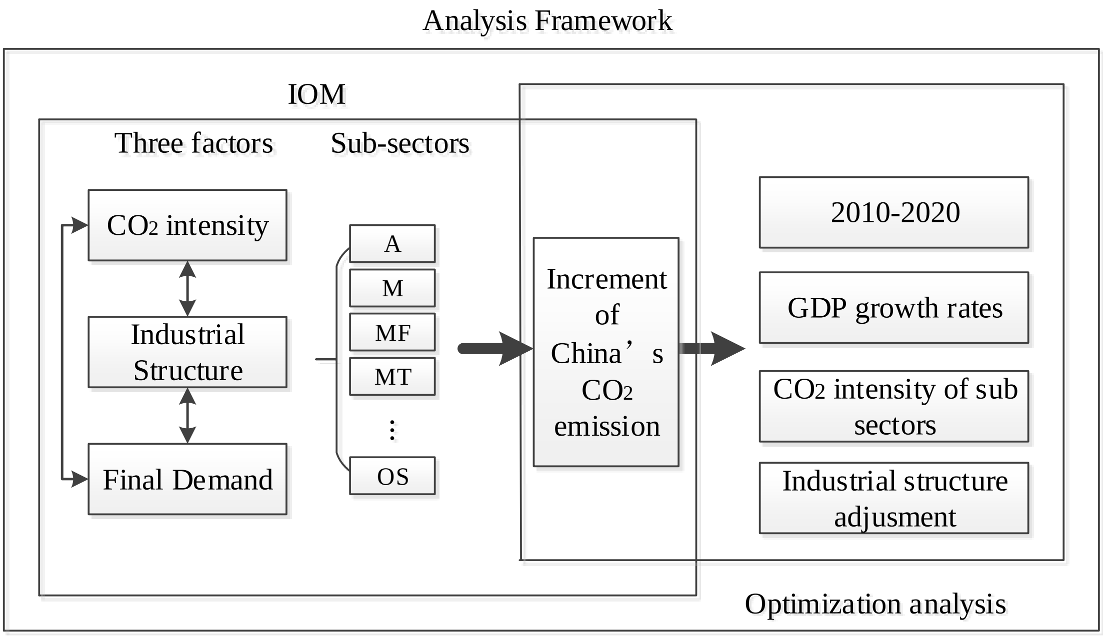


Fig. 1 Framework of this paper

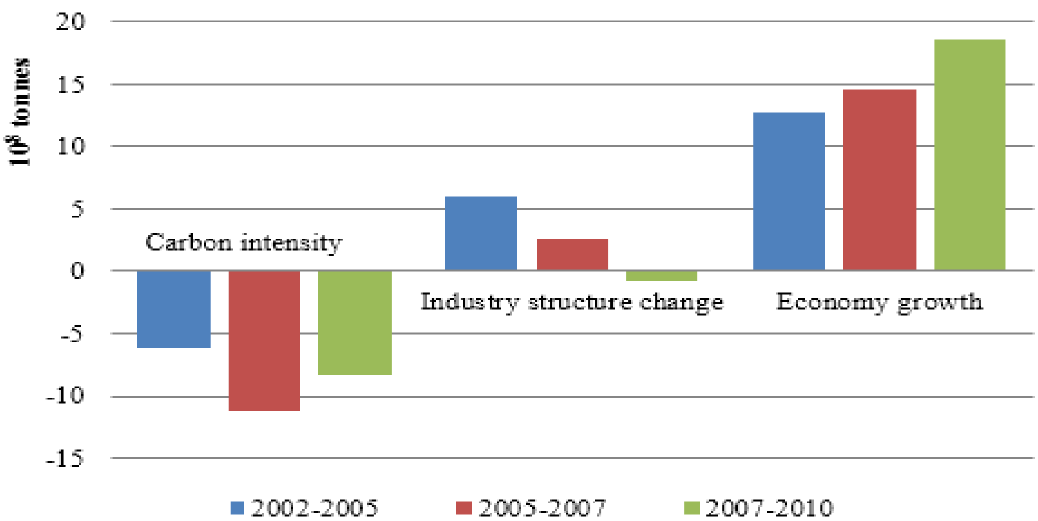


Fig. 2 Impacts of three factors on the increment of China’s CO_2 emissions

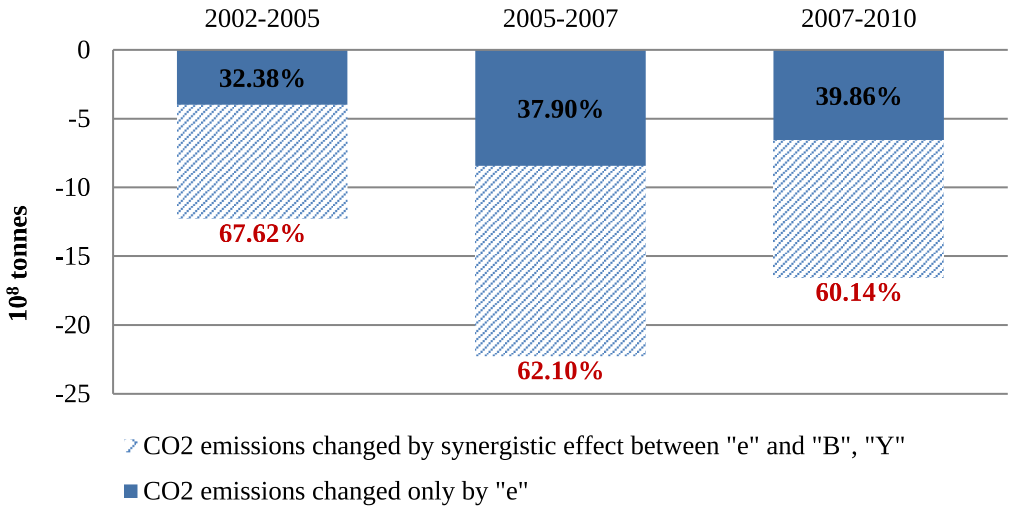


Fig. 3 Direct and indirect impacts of factor “e” on China’s CO_2 emissions

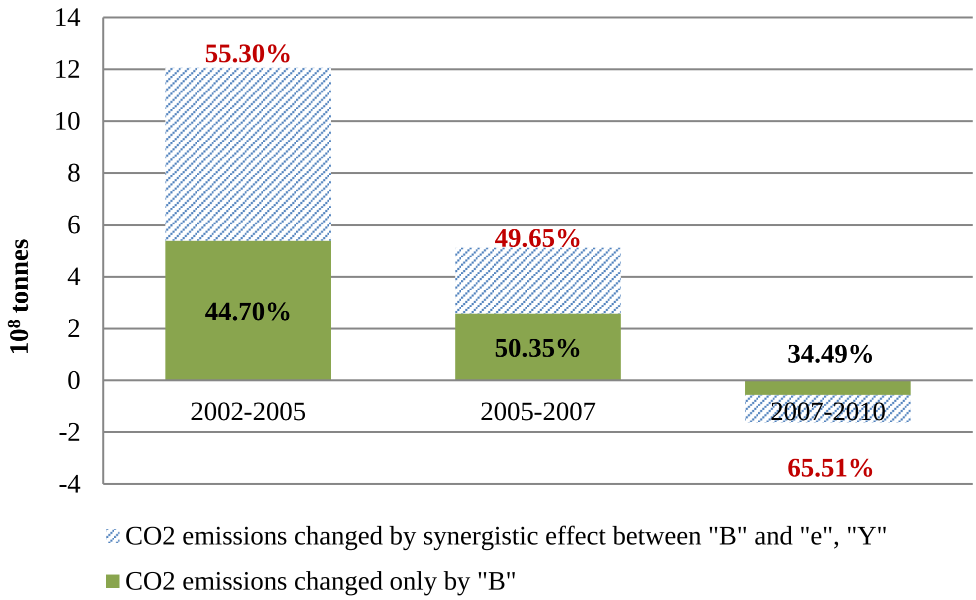


Fig. 4 Direct and indirect impacts of factor “B” on China’s CO_2 emissions

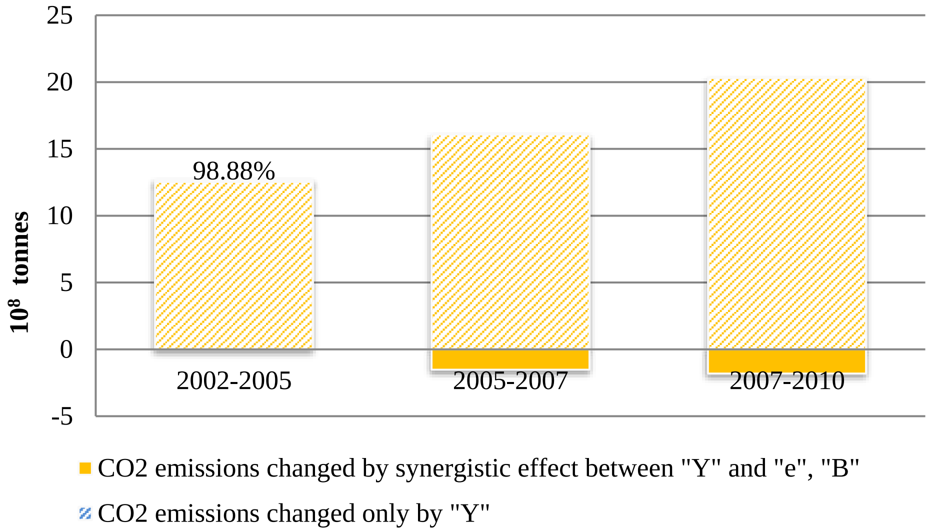


Fig. 5 Direct and indirect impacts of factor “Y” on China’s CO_2 emissions

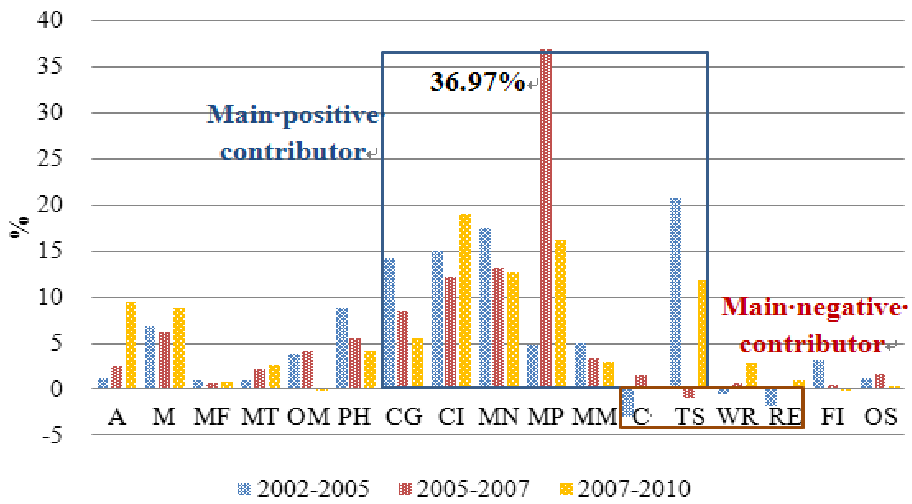


Fig. 6 Impacts of factor “e” on China’s CO_2 emissions from sector perspective

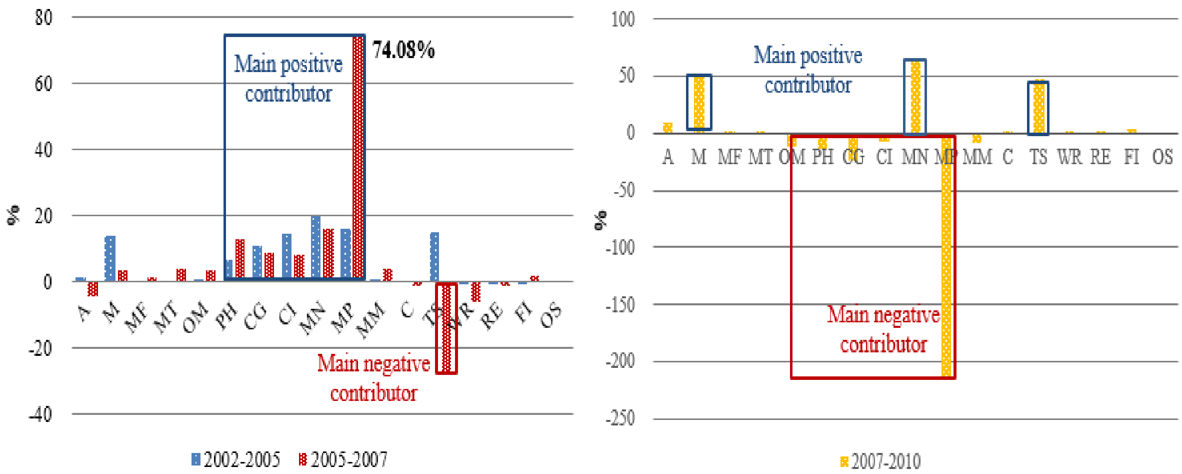


Fig. 7 Impacts of factor “B” on China’s CO_2 emissions from sector perspective

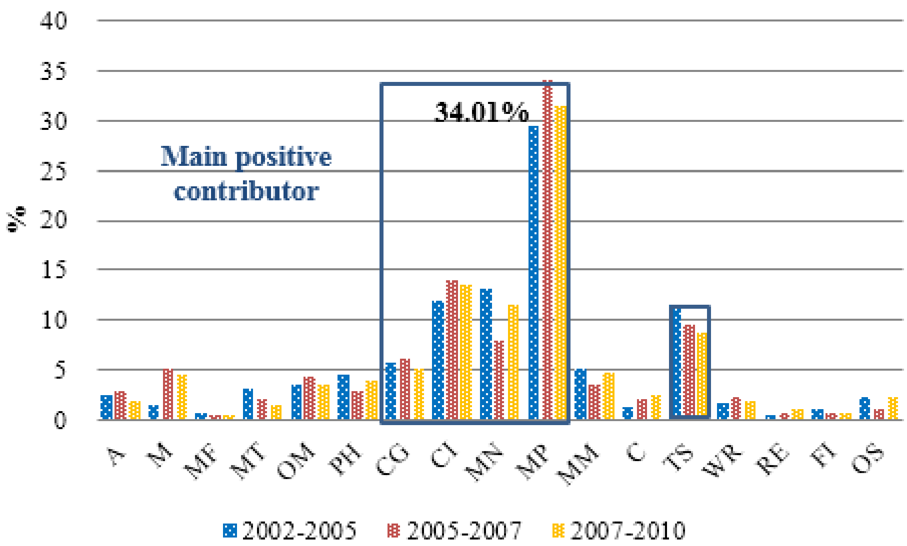


Fig. 8 Impacts of factor “Y” on China’s CO_2 emissions from sector perspective

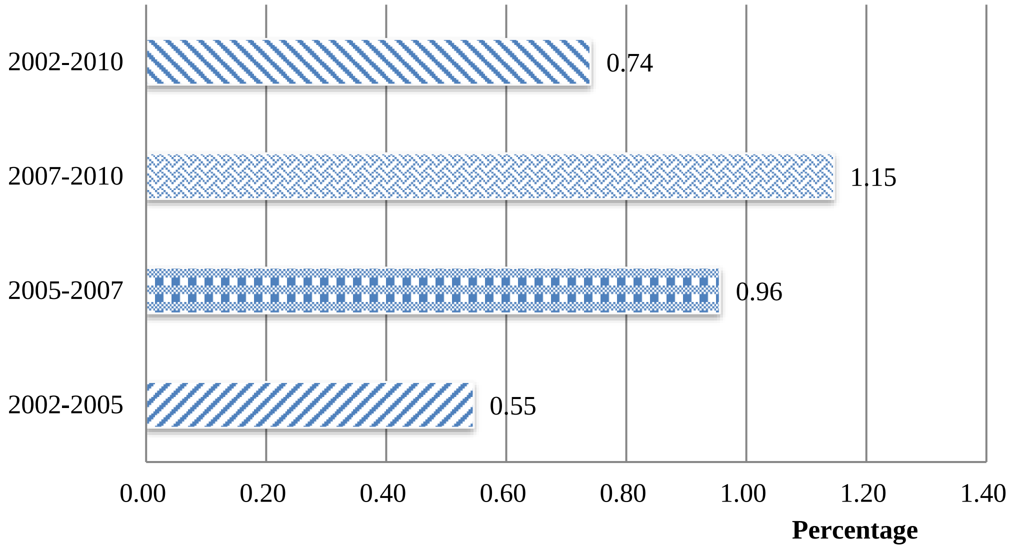
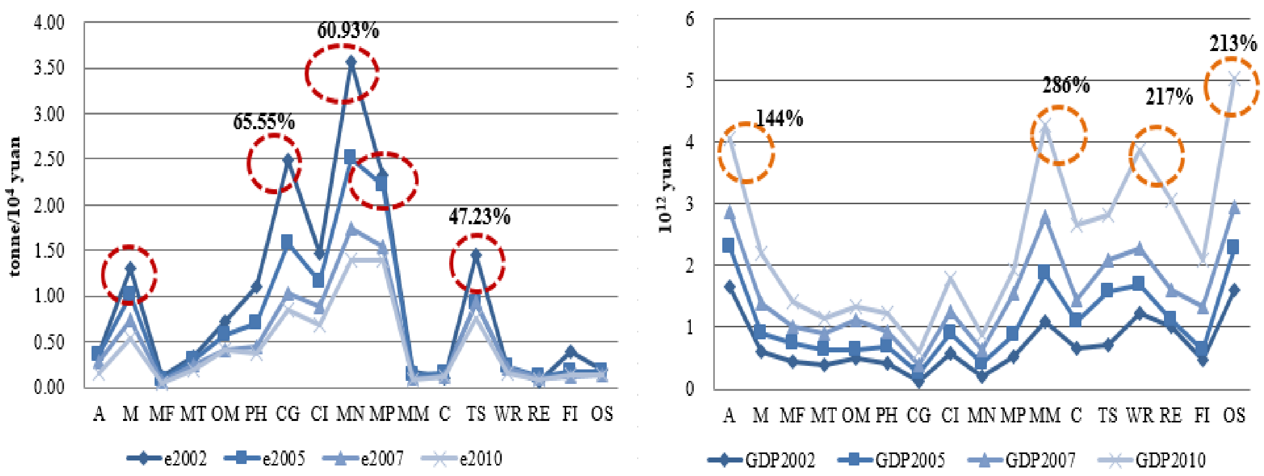


Fig. 9 Comparison of the CO_2 increments caused by GDP growth with the decrease in carbon intensity



(a) Trends of CO_2 intensity (b) Trends of GDP of sub-sectors

Fig. 10 Historical trends of CO_2 intensity and GDP of sub-sectors

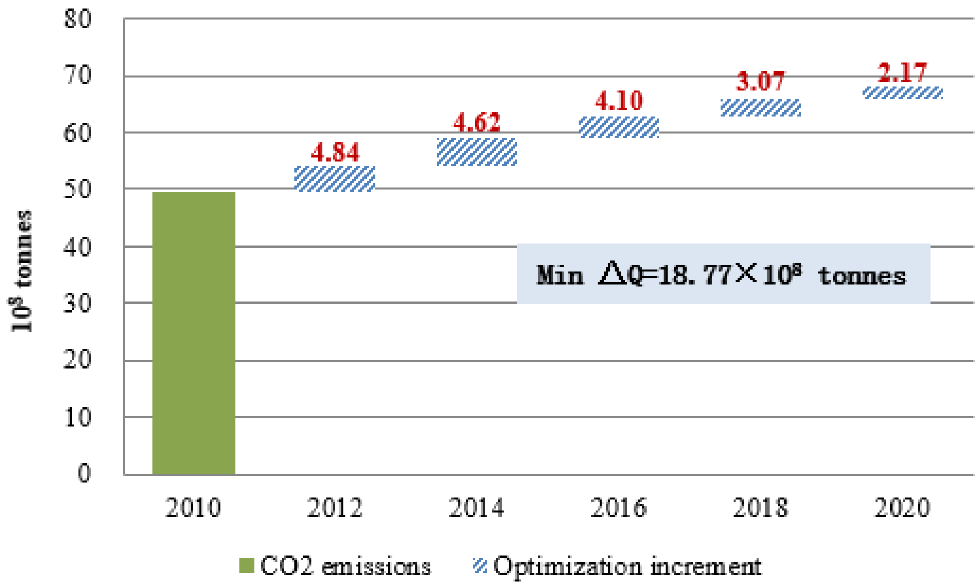
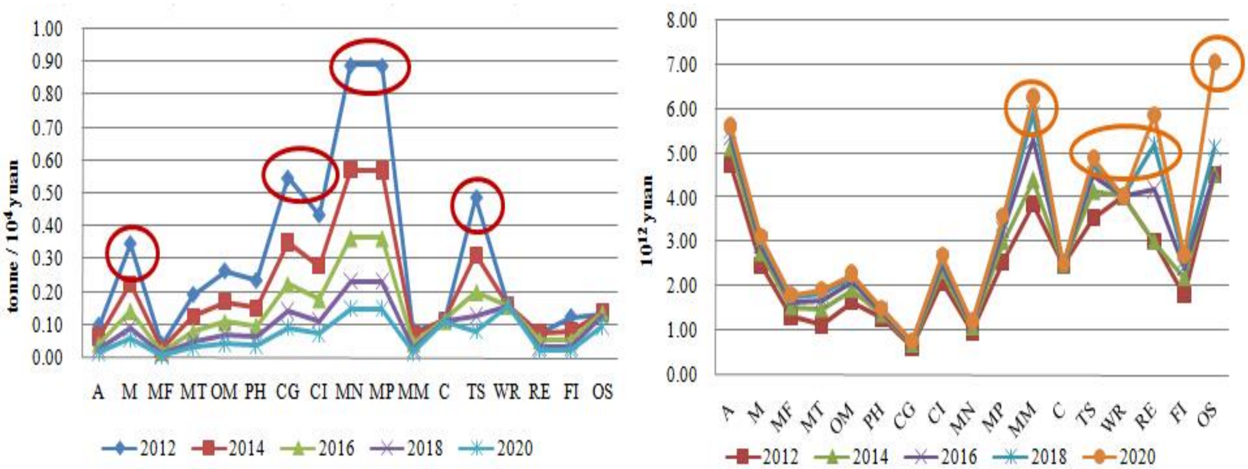


Fig. 11 Optimisation results for increments of China's CO_2 emissions



(a) Results of CO_2 intensity (b) Results of GDP

Fig. 12 Optimisation results of CO_2 intensity and GDP

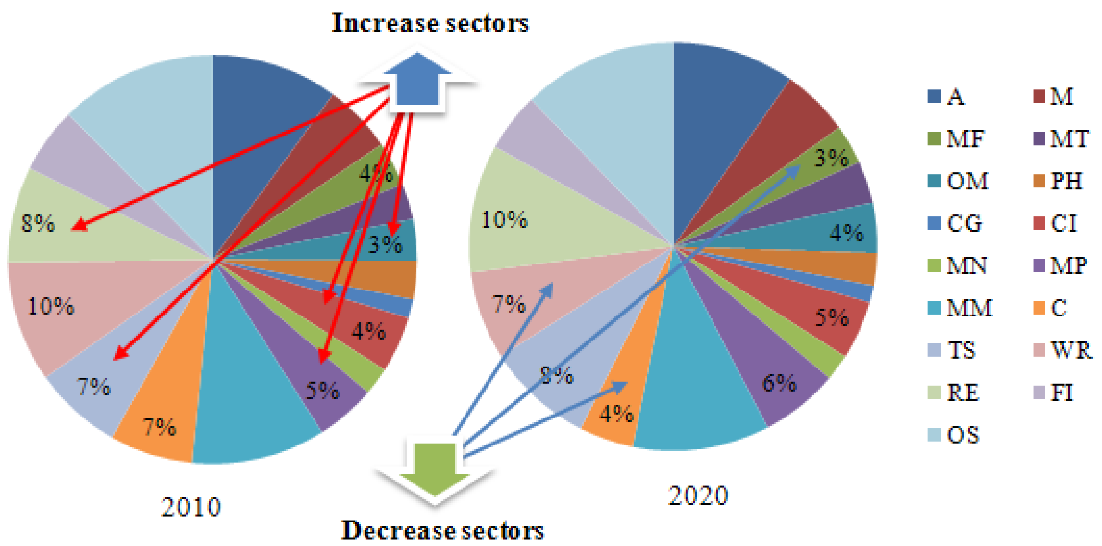


Fig. 13 Comparison of optimisation results for industrial structure

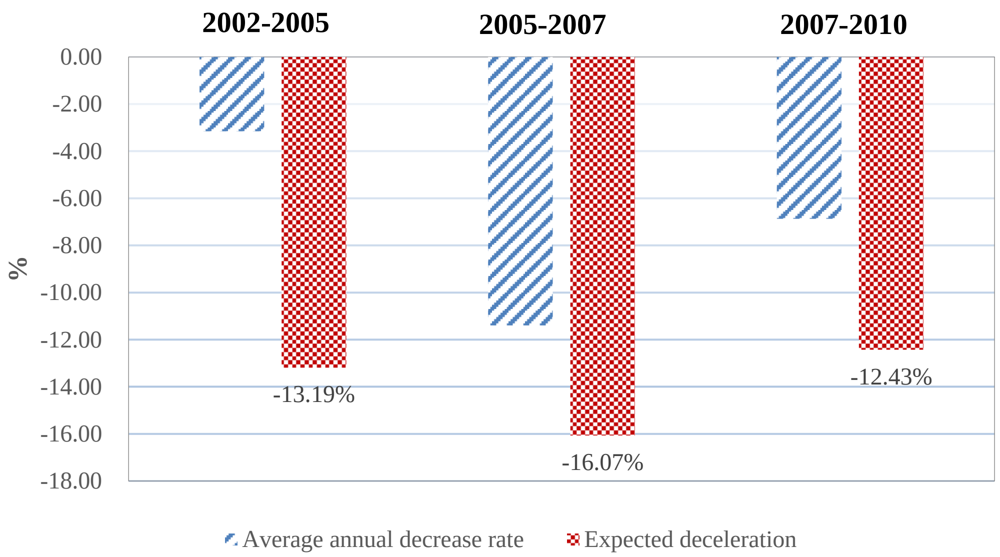


Fig. 14 Requirements for China's total CO_2 emission reduction under certain conditions