Environ Sci Pollut Res (2014) 21:13000–13006
DOI 10.1007/s11356-014-3250-8

RESEARCH ARTICLE

Decomposition of China's CO_2 emissions from agriculture utilizing an improved Kaya identity

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Received: 29 March 2014 / Accepted: 23 June 2014 / Published online: 5 July 2014

Abstract In recent decades, China's agriculture has been experiencing flourishing growth accompanied by rising pesticide consumption, fertilizer consumption, energy consumption, etc. and increasing CO_2 emissions. Analyzing the driving forces of agricultural CO_2 emissions is key requirements for low-carbon agricultural policy formulation and decomposition analysis is widely used for this purpose. This study estimates the agricultural CO_2 emissions in China from 1994 to 2011 and applies the Logarithmic Mean Divisia Index (LMDI) as the decomposition technique. Change in agricultural CO_2 emissions is decomposed from 1994 to 2011 and includes a measure of the effect of agricultural subsidy. Results illustrate that economic development acts to increase CO_2 emissions significantly. Agricultural subsidy acts to reduce CO_2 emissions effectively and has increased in recent years. Policy is needed to significantly optimize agricultural subsidy structure and change agricultural development pathway, if China's low-carbon agriculture target is to be achieved. This requires not only decreasing pesticide consumption, fertilizer consumption, energy consumption, etc. but also transformation of China's agricultural development path for optimal outcomes.

Keywords CO_2 emissions · Agriculture · Decomposition · Agricultural subsidy · China

Responsible editor: Gerhard Lammel

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Introduction

With the rapidly rising of global average temperature, global warming has become a focus of many countries. Many experts have contributed the root reasons of global warming to rapid global economy growth, large amounts of energy consumption, and increasing CO_2 emissions. According to the Environmental Kuznets Curve (EKC) hypothesis, further economic growth will overcome the environmental degradation. However, there is no critique suggesting that the EKC concept can be valid (Kaika and Zervas 2013a, b). China has become the world's biggest emitter of carbon dioxide with rapid economic growth and increasing energy consumption, and agriculture is a large contributor to CO_2 emissions. Agricultural CO_2 emissions are the CO_2 emissions in the agricultural production process (Johnson 2007). As a big agricultural country in the world, China's agricultural CO_2 emissions increased sharply from 46.33 million tons in 1994 to 85.75 million tons in 2011. In Europe, CO_2 emissions from agriculture are 10 % of the total annual CO_2 emissions (Robaina-Alves and Moutinho 2014). In the UK, the production processing and retailing of food were estimated to produce approximately 20 % of the national CO_2 emissions (Franks and Hadingham 2012). In our study, the CO_2 emissions estimated from agricultural production process to produce approximately 15 % of national CO_2 emissions and the ratio of agricultural CO_2 emissions to national CO_2 emissions continued to increase in recent years. In order to actively respond to climate change and to develop low-carbon economy, China has an ambitious target to reduce CO_2 emission intensity by 40–45 % by 2020, from 2005 levels. It is widely accepted that agriculture plays an important role in achievement of the goals of decreasing national CO_2 emissions (Luc et al. 2012; Michal et al. 2013; Francesco et al. 2013). Therefore, the success or failure of decreasing agricultural CO_2 emissions will have a significant effect on achieve these ambitious targets. Agricultural CO_2 emissions in China has become a focus of policy makers, and analyses of driving forces of agricultural CO_2 emissions constitute a vital part of low-carbon agriculture.

Logarithmic Mean Divisia Index (LMDI) theory was first proposed by Ang and Liu (2001) and has been widely used in decomposing changes in CO_2 emissions due to its perfect decomposition, consistency in aggregation, path independency, and an ability to handle zero values (Ang 2005). LMDI model is applied to study energy consumption and CO_2 emissions in the world (Peters and Hertwich 2008; Pani and Mukhopadhyay 2010). Greening et al. (2001) and Greening (2004) conducts the secondary decomposition of CO_2 emissions from sectors. Based on completed decomposition technique, many scholars study CO_2 emissions in different countries, such as the UK (Kwon 2005), South Korea (Oh et al. 2010), Thailand (Bhattacharyya and Ussanarassamee 2004), Brazil (Luciano and Shinji 2011), India (Paul and Bhattacharya 2004), Greece (Hatzigeorgiou et al. 2011), Turkey (Tunc et al. 2009), and Ireland (Tadhg 2013). Completed decomposition technique is also applied to research energy-related CO_2 emissions in China (Sun et al. 2010; Xu et al. 2012; Li and Ou 2013; Zhang et al. 2013).

Recent studies have analyzed CO_2 emissions and related problems in the national level and industry sector. However, few studies analyze the driving forces of agricultural CO_2 emissions. In this paper, we estimate China's agricultural CO_2 emissions based on six kinds of main carbon sources in agricultural production process and analyze the trend of China's agricultural CO_2 emissions from 1994 to 2011. An extended Kaya identity and LMDI method were applied to identify, quantify, and explain major driving forces acting on change China's agricultural CO_2 emissions. It is the first study to measure the impact of agricultural subsidy excitation and agricultural subsidy intensity on agricultural CO_2 emissions. The paper is organized as follows. "Decomposition methodology" details the decomposition methodology adopted. "Data" describes the data used. "Results and discussion" estimates and describes China's agricultural CO_2 emissions and discusses the results from decomposition analysis. "Conclusions and policy recommendations" provided the major conclusions and policy implications.

Decomposition methodology

Kaya identity was first proposed by Professor Yoichi Kaya (1990) on Intergovernmental Panel on Climate Change (IPCC) in 1990. The "drivers" or "effects" leading to observed change in CO_2 are population effect, energy intensity effect, carbon emissions intensity effect, and economic development effect in the Kaya identity. The Kaya identity is expressed as follows.

$$C = \frac{C}{E} \times \frac{E}{\mathrm{GDP}} \times \frac{\mathrm{GDP}}{P} \times P$$
$$\mathrm{CE} = \frac{C}{E}, \mathrm{EI} = \frac{E}{\mathrm{GDP}}, G = \frac{\mathrm{GDP}}{P} \qquad (1)$$

where C, E, GDI, and P denote CO_2 emissions, energy consumption, gross domestic product, and population, respectively. CE, EI, G, and P denote CO_2 emission coefficient effect, energy intensity effect, the GDP per capita (affluence) effect, and population effect, respectively.

In this paper, agricultural CO_2 emissions is decomposed to predefined factors of CO_2 emission intensity effect, agricultural subsidy excitation effect, agricultural subsidy intensity effect, economic development (affluence) effect, and population effect based on real situation of agricultural production process in China as the following extended Kaya identity.

$$C = \frac{C}{\mathrm{YA}} \times \frac{\mathrm{YA}}{\mathrm{IA}} \times \frac{\mathrm{IA}}{Y} \times \frac{Y}{P} \times P = \mathrm{CI} \times \mathrm{OE} \times F \times G \times P \qquad (2)$$

The following variables are applied in Eq. (2).

C	Total agricultural CO_2 emissions
YA	Agricultural subsidy excitation
IA	Agricultural subsidy intensity
Y	GDP
P	Population
$\mathrm{CI} = \frac{C}{\mathrm{YA}}$	The CO_2 emission intensity in agricultural sector
$\mathrm{OE} = \frac{\mathrm{YA}}{\mathrm{IA}}$	The agricultural output per agricultural subsidies
$F = \frac{\mathrm{IA}}{Y}$	The ratio of agricultural subsidies to GDP
$G = \frac{Y}{P}$	The GDP per capita or affluence
P	Population

The decomposition of an observed change in C associated with these factors are referred to as, carbon emission intensity effect (ΔC_{cei}), agricultural subsidy excitation effect (ΔC_{ase}), agricultural subsidy intensity effect (ΔC_{asi}), affluence effect (ΔC_{ecm}), and population effect (ΔC_{pop}). The index of annual change in total agricultural CO_2 emissions (C_{tot}) can be expressed in an addition form as follows.

$$\Delta C_{\mathrm{tot}} = \Delta C_T - \Delta C_0 = \Delta C_{\mathrm{cei}} + \Delta C_{\mathrm{ase}} + \Delta C_{\mathrm{asi}} + \Delta C_{\mathrm{ecm}} + \Delta C_{\mathrm{pop}} \qquad (3)$$

LMDI analysis is then applied as the method to decompose Eq. (3). From Ang and Liu (2001), the following LMDI II formulae apply to each of the effects.

$$\Delta C_{\mathrm{cei}} = L\left(W^T, W^0\right) \times \ln\left(\frac{\mathrm{CI}^T}{\mathrm{CI}^0}\right) \qquad (4)$$

$$\Delta C_{\text{ase}} = L\left(W^T, W^0\right) \times \ln\left(\frac{\text{OE}^T}{\text{OE}^0}\right) \quad (5)$$

$$\Delta C_{\text{asi}} = L\left(W^T, W^0\right) \times \ln\left(\frac{F^T}{F^0}\right) \quad (6)$$

$$\Delta C_{\text{ecm}} = L\left(W^T, W^0\right) \times \ln\left(\frac{G^T}{G^0}\right) \quad (7)$$

$$\Delta C_{\text{pop}} = L\left(W^T, W^0\right) \times \ln\left(\frac{P^T}{P^0}\right) \quad (8)$$

Where $W = \text{CI} \times \text{OE} \times F \times G \times P$ and $L\left(W^T, W^0\right) = \left(W^T - W^0\right) / \left(\ln W^T - \ln W^0\right)$.

Data

This study collected annual data on the pesticide consumption, fertilizer consumption, agricultural diesel consumption, plastic sheeting consumption, tilling area, and actual irrigated area for 1994–2011 (presented in Appendix Table 3), from China Rural Statistical Yearbook (1995–2012). Agricultural subsidies, real GDP, and population from 1994 to 2011 were collected from Statistical Yearbook of the People's Republic of China (2012). The agricultural subsidies and real GDP were measured in China Yuan at 1994 prices.

Typically, agricultural CO_2 emissions comes from six areas: fertilizer consumption, pesticides consumption, plastic sheeting consumption, fossil fuels consumption for agricultural machinery (mainly agricultural diesel consumption), agricultural tilling, and electrical power consumption in agriculture irrigated. This study estimates agricultural CO_2 emissions in China from 1994 to 2011 as follows:

$$C = \sum_{i=1}^{6} C_i = \sum_{i=1}^{6} S_i \times \rho_i \quad (9)$$

Where C, C_i, S_i, and ρ_i denote total amount of agricultural CO_2 emissions, CO_2 emissions from source i, the amount of carbon source i consumption, and carbon emission coefficients for carbon source i of CO_2 emissions, respectively. The CO_2 emission coefficients of different sources of CO_2 emissions are given in Table 1.

Results and discussion

Agricultural CO_2 emission estimation

According to Eq. (9), Table 1, and Appendix Table 3, the trend of China's agricultural CO_2 emissions is presented in Fig. 1.

Figure 1 shows the changes in China's agricultural CO_2 emissions and agricultural CO_2 emission mix based on six sources of CO_2 emissions from 1994 to 2011. In recent years, China's agricultural CO_2 emissions continue to increase sharply in correlation to the levels of fertilizer consumption, pesticide consumption, plastic sheeting consumption, and agricultural diesel consumption. From 46.33 million tons in 1994 to 85.75 million tons in 2011, agricultural CO_2 emissions increased by approximately 85 %. Fertilizer consumption is the biggest contributor to China's agricultural CO_2 emissions followed by agricultural diesel consumption, plastic sheeting consumption, and pesticide consumption. From 1994 to 2011, China's fertilizer consumption increased sharply from 29.72 to 51.09 million tons, and the ratio of CO_2 emissions contributed by fertilizer consumption to total agricultural CO_2 emissions is approximately 60 %. With the accelerating of agricultural modernization, CO_2 emissions caused by agricultural diesel consumption, plastic sheeting consumption, and pesticide consumption continue to increase rapidly in recent years, and the annual average growth rates are 6.3, 8.8, and 4.6 %, respectively. According to the growth rate of CO_2 emissions, the changes of China's agricultural CO_2 emissions could be divided into four stages: 1994–1997, 1998–2003, 2004–2007, and 2008–2011.

The annual growth rate of China's agricultural CO_2 emissions surpasses 5 % in the 1994–1997 period. One reason for the rapid CO_2 emission growth is that a large amount of fertilizer was consumed in agricultural production process to improve the output per unit area. From 31.52 million tons in 1994 to 39.81 million tons in 1997, China's fertilizer consumption increased by approximately 20 % in only 4 years. The other reason for the rapidly increasing CO_2 emissions is the rapid process of agricultural modernization accompanied by rising agricultural diesel consumption.

In the 1998–2003 period, China's agricultural CO_2 emissions continued to increase slowly. The burden of farmers overweighs in China from 1998 to 2003. Many farmers gave up agricultural production and went to urban for work which had a negative impact on agricultural production sources demands and slowed down the increasing of agricultural CO_2 emissions. China's grain production was facing enormous challenges due to the decreasing output of grain.

Table 1 The CO_2 emission coefficients of different resources

Carbon sources	CO_2 coefficients	Reference
Fertilizer	0.8956 kg/kg	T.o. West and Marland (2002)
Pesticide	4.9341 kg/kg	Oak Ridge National Laboratory (Mosier et al. 1998)
Plastic sheeting	5.18 kg/kg	Institute of Biology and Technology in China Agricultural University (Wu et al. 2007)
Agricultural diesel	0.5927 kg/kg	IPCC
Agricultural tilling	312.6 kg/km^2	Institute of Biology and Technology in China Agricultural University (Wu et al. 2007)
Agricultural irrigated	25 kg/Cha	Dubey and Lal (2011)

The CO_2 emissions caused by agriculture irrigated are contributed to thermal power consumption. According to the electricity production structure in China (the average ratio of thermal power generation is 81.9 % in the 1994–2011 period), the CO_2 emission coefficients of agriculture irrigated adopted in this paper is 20.476 kg/hm^2

During 2004–2007, China's agricultural CO_2 emission growth was accelerated. In 2004, China's government promulgated the policies of "two tax breaks, three subsidies" for agriculture in the central committee of the Chinese communist party which greatly improved the farmers' enthusiasm for agricultural production process. Two tax breaks policy is deductions and exemptions of agricultural tax and agricultural special tax except tobacco tax, and three subsidies policy is the direct subsidy, seed variety subsidy, and purchase sublimations for large farm machinery to farmers who produce gains.

Faced with the serious environmental pollution and climate changes, Chinese government realized the importance of resources conservation and environmental protection and advocated low-carbon agriculture and green agriculture since 2008. China began to promote the use of biogas, solar, and other renewable energy consumption in rural areas, and decreased fertilizer consumption, pesticide consumption, and plastic sheeting consumption to control China's agricultural CO_2 emissions.

Results

The complete time-series decomposition results for China's agricultural CO_2 emissions are presented in Appendix Table 4 based on the extended Kaya identity established in "Decomposition methodology" and China's agricultural CO_2 emissions data estimated in "Results and discussion." The accumulated effects by period are available in Table 2 and Fig. 2.

The accumulated effects over the entire period (Fig. 2) illustrate that the dominant positive effect is economic development effect, as is often identified in other studies (Tadhg et al. 2012; Chen et al. 2013; Xu et al. 2012; Xiaoli et al. 2012). The population effect as a scale effect also had a positive but relatively small effect on emissions. Agricultural

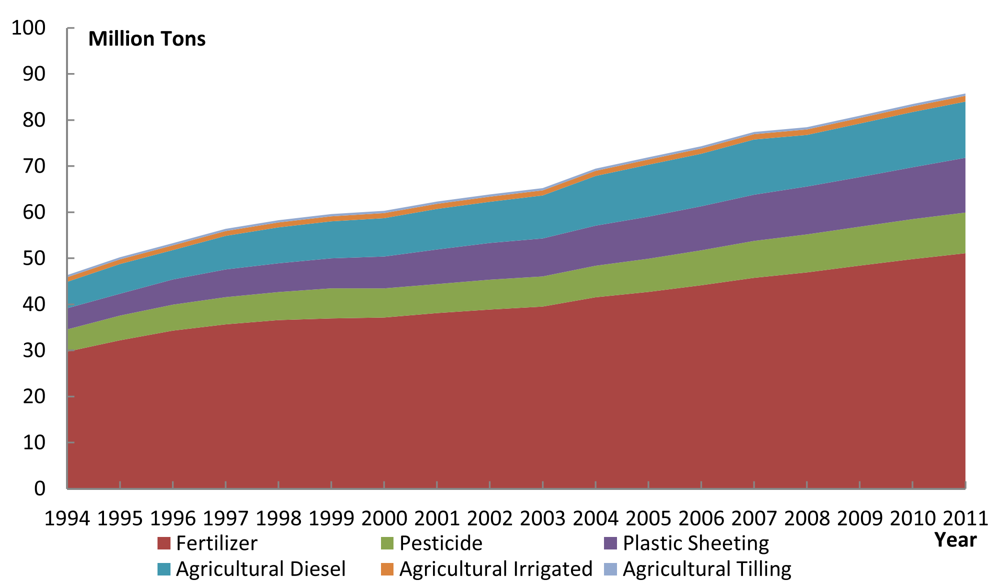

Fig. 1 Agricultural CO_2 emissions of six carbon sources in China from 1994 to 2011

Table 2 Decomposition of China's agricultural CO_2 emissions from 1994 to 2011

Year	ΔC_{tot}	ΔC_{cei}	ΔC_{ase}	ΔC_{asi}	ΔC_{ecm}	ΔC_{pop}
1994–1997	10.05	3.23	−1.74	−6.25	13.21	1.60
1998–2003	8.84	−1.27	−36.27	16.34	27.35	2.68
2003–2007	12.19	−1.88	−35.30	16.56	31.22	1.59
2008–2011	8.35	−5.95	−40.37	24.80	28.29	1.58
1994–2011	39.42	−5.87	−113.68	51.45	100.07	7.45

subsidy intensity effect, as a significant positive in general, had a fluctuant effect on emissions. The agricultural subsidy excitation effect was the most significant negative effect on emissions, while CO_2 emission intensity had a small negative effect also. The total negative effects are heavily outweighed by the total positive effects, which resulted in the increase in agricultural CO_2 emissions. These decomposition results of China's agricultural CO_2 emissions from 1994 to 2011 are summarized as follows:

(1) The scale effects (economic development effect and population effect) are the dominant drivers in China's agricultural CO_2 emissions. Economic development effect has a great effect on emissions, and population effect has a weak effect on emissions.

(2) The intensity effect (CO_2 emission intensity effect) reducing the intensity of CO_2 emissions per unit agricultural output is a weak factor in limiting increasing in emissions.

(3) Agricultural subsidy effects (agricultural subsidy intensity effect and agricultural subsidy exCitation effect) have different effects on emissions. Agricultural subsidy intensity effect is the most significant factor in driving growth in China's agricultural CO_2 emissions. The agricultural subsidy excitation effect contributes to decreasing emissions effectively. The impact of agricultural subsidy intensity effect to emission changes with the variation of agricultural subsidy intensity. Between 1994 and 1998, in order to increase grain production, China increased agricultural subsidies and formulated policies to reduce the burden of farmers and ensure grain purchase. A lot of fertilizer, pesticide, plastic sheeting, etc. were adopted in agricultural production process accompanied by rising CO_2 emissions. Agricultural subsidy intensity effect had a positive effect on agricultural CO_2 emissions from 1994 to 1998. During 1999 and 2003, China's government decreased agricultural subsidy intensity and formulated policies to accelerate the reform of agricultural industry and widen the ways to increasing farmers' income. In the 1999–2003 period, the positive effect of agricultural subsidy intensity to CO_2 emissions became weak and CO_2 emissions continued to increase at a slow growth rate. China's government improved agricultural subsidy intensity to promote the development of green agriculture and circular agriculture since 2004. Agricultural subsidy intensity effect played a significant factor in driving growth in CO_2 emissions.

(4) The total positive effects heavily exceeded the total negative effects, which resulted in the rapidly increasing agricultural CO_2 emissions.

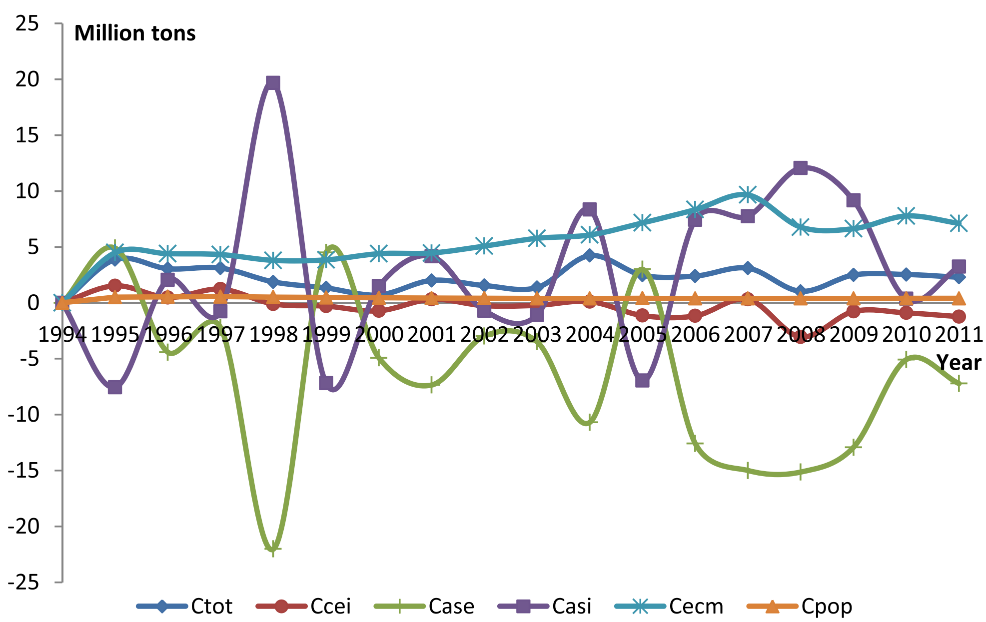

Fig. 2 Accumulated decomposition of China's agricultural CO_2 emissions 1994–2011

Conclusions and policy recommendations

Understanding the driving forces of agricultural CO_2 emissions is essential for policy-making process. In this paper, it is attempted to decompose the driving forces of agricultural CO_2 emissions. The decomposition analysis reveals the following important conclusions. First, the positive effects for agricultural CO_2 emissions are economic development effect, population effect, and agricultural subsidy intensity effect. Second, the negative effects for agricultural CO_2 emissions are agricultural subsidy excitation effect and CO_2 emissions intensity. Third, agricultural subsidy excitation effect had a significant negative effect on CO_2 emissions. The total positive effects heavily outweigh the total positive effects, which resulted in agricultural CO_2 emissions increasing. Therefore, low-carbon agriculture should be paid more efforts to reduce China's agricultural CO_2 emissions, and some policy suggestions are presented as follows.

(1) Improving efficiency of agricultural sources and decreasing fertilizer consumption and pesticide consumption

In traditional agricultural production process, agricultural output was heavily relied on the fertilizer consumption and pesticide consumption which led to a rapid increasing in agricultural CO_2 emissions. China should increase investment in agricultural science and technology innovation, which could promote the popularization of economizing farming, planting, fertilizing, spraying irrigation, and other low-carbon farming techniques. New scientific and technological means should be adopted widely in rural area to improving efficiency of agricultural sources and inhibit agricultural CO_2 emission growth.

(2) Increasing agricultural subsidies

Agricultural subsidies play an important role in decreasing agricultural CO_2 emissions and guide the development way of agriculture. China should increase agricultural subsidies and accelerate agricultural infrastructure construction, which can provide basic guarantee for development of low-carbon agriculture. Increasing agricultural subsidy intensity could encourage farmers to join in the development of low-carbon agriculture and circular agriculture and achieve the goal of agricultural sustainable development.

Acknowledgments This study was supported by the Soft science research base of Hebei province.

Appendix

Table 3 Annual time series of six carbon sources in China's agriculture from 1994 to 2011

Year	Fertilizer Unit: million tons	Pesticide	Plastic sheeting	Agricultural diesel	Agricultural irrigated Unit: thousand km^2	Agricultural tilling
1994	33.18	0.98	0.89	9.67	487.59	1,482.41
1995	35.94	1.09	0.92	10.88	492.81	1,498.79
1996	38.28	1.14	1.06	10.76	503.81	1,523.81
1997	39.81	1.20	1.16	12.29	512.39	1,539.69
1998	40.84	1.23	1.21	13.15	522.96	1,557.06
1999	41.24	1.32	1.26	13.54	531.58	1,563.73
2000	41.46	1.28	1.34	14.05	538.20	1,563.00
2001	42.54	1.28	1.45	14.85	542.49	1,557.08
2002	43.39	1.31	1.54	15.08	543.55	1,546.36
2003	44.12	1.33	1.59	15.75	540.14	1,524.15
2004	46.37	1.39	1.68	18.20	544.78	1,535.53
2005	47.66	1.46	1.76	19.03	550.29	1,554.88
2006	49.28	1.54	1.85	19.23	557.50	1,521.49
2007	51.08	1.62	1.94	20.21	565.18	1,534.64
2008	52.39	1.67	2.01	18.88	584.72	1,562.66
2009	54.04	1.71	2.08	19.60	592.61	1,586.14
2010	55.62	1.76	2.17	20.23	603.48	1,606.75
2011	57.04	1.79	2.30	20.57	616.82	1,622.83

Table 4 Annual time-series decomposition results from 1994 to 2011. Unit: million tons

Year	ΔC_{tot}	ΔC_{cei}	ΔC_{ase}	ΔC_{asi}	ΔC_{ecm}	ΔC_{pop}
1994–1995	3.8808	1.5266	4.9021	−7.5501	4.4932	0.5089
1995–1996	3.0509	0.4778	−4.4178	2.0574	4.3949	0.5386
1996–1997	3.1148	1.2297	−2.2257	−0.7612	4.3209	0.5511
1997–1998	1.8720	−0.0990	−22.0353	19.6845	3.7982	0.5237
1998–1999	1.3340	−0.2929	4.5016	−7.2010	3.8442	0.4820
1999–2000	0.7044	−0.7170	−4.9191	1.4891	4.3972	0.4543
2000–2001	2.0110	0.3185	−7.3548	4.1604	4.4609	0.4260
2001–2002	1.5485	−0.2544	−2.9756	−0.7040	5.0757	0.4069
2002–2003	1.3682	−0.2251	−3.4852	−1.0865	5.7774	0.3876
2003–2004	4.2278	0.1157	−10.6927	8.3378	6.0718	0.3952
2004–2005	2.4606	−1.1422	2.9930	−6.9619	7.1555	0.4163
2005–2006	2.3968	−1.1695	−12.5951	7.4375	8.3381	0.3858
2006–2007	3.1003	0.3127	−15.0033	7.7458	9.6532	0.3919
2007–2008	1.0333	−3.0486	−15.1385	12.0534	6.7711	0.3959
2008–2009	2.4935	−0.7719	−12.9239	9.1668	6.6347	0.3878
2009–2010	2.5363	−0.9013	−5.0848	0.3557	7.7729	0.3938
2010–2011	2.2888	−1.2328	−7.2252	3.2277	7.1138	0.4053

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