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Research article

Preventing a rebound in carbon intensity post-COVID-19 – lessons learned from the change in carbon intensity before and after the 2008 financial crisis ☆

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A B S T R A C T

The carbon emission rebound of the post-2008 financial crisis teaches us a lesson that avoiding a rebound in carbon intensity is key to prevent the carbon emission increase afterward. Although how carbon emission will change the world after the COVID-19 pandemic is unknown, it is urgent to learn from the past and avert or slow down the potential rebound effect. Therefore, this study aims to identify key drivers of carbon intensity changes of 55 sectors, applying the decomposition techniques and the world input-output data. Our results demonstrate that global carbon intensity fluctuates drastically when shocked by the global financial crisis, presenting an inversed-V shape for the period 2008–2011. Industrial carbon emission and gross output vary among different industries, the growth rate of industrial carbon intensity varies from -55.55% to 23.77%. The energy intensity effect and economic structure effect have opposite impacts on carbon intensity decrease, accelerating and hindering the decreasing carbon intensity, respectively. However, the energy mix effect has a minor impact on carbon intensity decrease. The industrial carbon intensity decomposition results show the impact of technological and structural factors are significantly different among industries. Moreover, the impact of energy intensity is slightly stronger than the energy mix. More measures targeting avoiding the rebound in carbon intensity should be developed.

1. Introduction

Similar to the 2008 financial crisis, the COVIID-19 pandemic has also caused a huge impact on global carbon emissions. International Energy Agency (IEA) expects that the global CO_2 emissions to drop by 8% (~2.6 gigatonnes (Gt) CO_2) in 2020 as the COVID-19 shuts down many economic activities. The decrease of CO_2 emission from the COVID-19 pandemic is six times greater than that of the 2008 financial crisis, with 0.4 gigatonnes CO_2 drop (IEA, 2020). Le Quérél, et al., found that an abrupt 8.8% decrease in global CO_2 emissions (or about 1.55 Gt CO_2) in the first half of 2020 compared to the same period in 2019 by estimating country-level daily CO_2 emissions of different sectors. Such a year-by-year reduction would be the largest ever, including a decrease in CO_2 emission caused by previous economic downturns or World War II (Le Quéré et al., 2020). It is still unknown that what the carbon emission will change after the pandemic, partly due to the second wave of COVID-19 pandemic has been sweeping the world in winter, causing more damage than the first wave of the pandemic in spring (WHO, 2020). However, we can learn some lessons from the changes in carbon emissions after the 2008 financial crisis. Global CO_2 emissions increased by a record 5.9% in 2010 and a 1.4% decrease comes as follows in 2009 as the consequence of the post effects of the 2008 Global Financial Crisis. This is also the highest annual growth rate since 2003 (and previously 1979) (Peters et al., 2012).

Meanwhile, many governments are now proposing economic recovery plans for post pandemic, with economic stimulus allocation of trillion dollars (IMF, 2020). And huge stimulus plans will bring increase for CO_2 emissions. After the 2008 global financial crisis, many countries strived to recovery economy. Excessive quantitative easing fiscal policy was introducing by increasing the supply of currency or liquid funds, which encourages consumption and loan. Specifically, developing countries, like China, paid attention to fiscal policies. The outbreak of financial crisis heavily hit China's export of good. Therefore, China switched to

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Nomenclature

CI	Global carbon intensity
i	Industry
C	Carbon emission
E	Energy consumption
O	Gross output
CE	Energy mix
EI	Energy intensity
OS	Economic structure
${D_{CE}}^{t,t+1}$	Energy mix effect in single-period
${D_{EI}}^{t,t+1}$	Energy intensity effect in single-period
${D_{OS}}^{t,t+1}$	Economic structure effect in single-period
${D_{CE}}^{0,T}$	Energy mix effect in multi-period
${D_{EI}}^{0,T}$	Energy intensity effect in multi-period
${D_{OS}}^{0,T}$	Economic structure effect in multi-period

promote domestic demand by increasing fiscal subsidies and lowering purchase tax. These actions made it a priority to recovery economy while caring less about energy consumption and carbon emission. Developed countries acted rapidly to resist the financial crisis. The United states, the original country of financial crisis, took targeted monetary policy and unconventional policies to intervene in the financial market and took financial policy of reducing taxes to aid real economy. The above actions promoted economic growth and relieved financial crisis temporarily. Actually, whether developed or developing countries applied fiscal policy, monetary policy, and regulatory policy together to recovery economy, which concerned economic growth instead of environmental protection. Hence, economic development creates opportunities as well as challenge(Song and Li, 2020). Economic growth after extreme events, especially is connected with energy consumption and carbon emission, which furthermore influenced carbon intensity. Indeed, both researchers and policymakers are concerned the rebound in carbon emission(Carbon Brief, 2020). The exiting studies of decomposition of the rebound in carbon emission post-2008 finical crisis showed that the rapidly increase in carbon intensity contributed to the rebound in carbon emission post-2008 financial crisis for the world (Jotzo et al., 2012; Peters et al., 2012), and country level, China(Mi et al., 2017), the United States(Feng et al., 2015), etc. (López et al., 2014; Wang and Wang, 2020b). A better understanding of the carbon intensity changes and the driving factors of the change could contribute to avoid the rebound in carbon emission post-COVID-19 pandemic. Therefore, our study is aimed to investigate the driver of change in carbon intensity by decomposing the change in carbon intensity at sector-level.

Increasingly, more and more countries concern environment protection and economic development due to severe environment pollution(Song et al., 2019). However, beyond carbon emission, a number of scholars put eyes on the study of carbon intensity recently (Xu et al., 2017; Wang et al., 2018; Azam et al., 2021). Actually, there is a bunch of literatures about carbon intensity covering a wide range from cities and provinces (Huang, 2018; Tang et al., 2021; Cai et al., 2021; Yu and Zhang, 2021), country (Zhou et al., 2019; Xiao et al., 2019, 2020; Tian et al., 2021), to even globe (Bhattacharya et al., 2020; Ikegami and Wang, 2021; Wang and Wang, 2021). Focusing on Chinese cities, Zhang et al. made a comprehensive empirical research to uncover the impact of industrial structure and technical progress on carbon intensity in 2006–2016, and they found technical progress significantly promotes carbon intensity decrease, while carbon emissions rebound effect weakens the positive impact of technical progress (Zhang et al., 2020). Cheng and Yao applied the panel estimation methods to evaluate how renewable energy technology innovation impacts Chinese carbon intensity. The results demonstrated renewable energy technology innovation has no influence on carbon intensity in a short term. However, it has remarkable and negative impact in a long term (Cheng and Yao, 2021). Yin et al. tried to explore the causal relationship between Chinese carbon intensity and energy structure, and they found the adjustment of energy structure causes a negative impact on Chinese carbon intensity (Yin et al., 2021). Huang et al. combined the carbon intensity decomposition analysis with the structural evolution of demographic factors, in this way to study how various factors (like acknowledge, institutional human capital, regional heterogeneity) impact carbon intensity (Huang et al., 2021). Li and Ouyang exerted efforts to figure out the effect of endogenous technical progress on Chinese carbon intensity goal reducing.[1] They found that the combination of carbon tax and technological progress makes the established goal come true, though it hinders economic growth (Li and Ouyang, 2021). Obviously, scholars have done abundant work on exploring factors influencing carbon intensity, but what have been done more falls in cities and country level. For global level, scholars prefer to study what driving global carbon emission change (Wang and Wang, 2020a; Li et al., 2021; Chen and Lee, 2020). Since carbon reduction becoming a global consensus, it is necessary to figure out how global carbon intensity changes and what factors promoting or inhibiting global carbon intensity decrease the most.

Excepting macro-level studies, there is a lot of relevant work done on industrial level (Wang et al., 2018; Ma et al., 2019, 2020b). However, previous researches tended to concern single sector or several specific sectors (Huang et al., 2020; Azam et al., 2021; Wang and Wang, 2020b). Wang et al. discovered that the development of 21 industries promote Chinese carbon intensity decrease, while the remaining 7 industries do not (Wang et al., 2020a). Ye et al. detected that technological gap is able to influencing carbon intensity through global value chain. Excepting concerning its own technological progress, a county shall be interested in the development of global frontier technologies as well as the speed of technological progress (Ye et al., 2020). Wang et al. paid attention on carbon intensity inequality in the electricity sector. The results demonstrated that intraregional inequality is the primary contributor to carbon intensity inequality (Wang et al., 2020b). Liu et al. concentrated on transport sector, and investigated both regional differences and driving factors of carbon intensity in Chinese 30 provinces. They found energy intensity effect has a strong and positive impact on carbon intensity (Liu et al., 2021a). Liu et al. investigated the impact of Artificial Intelligence on carbon intensity in Chinese industrial sector (Liu et al., 2021b). It is easy to find that previous carbon intensity studies did not involve as many sectors as possible. In fact, carbon reduction policies that suitable for one sector may be not suitable for another sector. Hence, it is necessary to realize how industrial carbon intensity changes involving as many sectors as possible, which enables policy-makers to formulate and implement specific industrial-level carbon reduction policies.

It is widely acknowledged that there are differences among various industrial carbon intensity, which indicates that great heterogeneity exists among sectors when it comes to carbon intensity. However, existing studies more focus on regional disparity (Wang et al., 2019; Chuai and Feng, 2019; Yu et al., 2019). Song and Wang decomposed provincial energy efficiency from the perspective of government regulation and technological progress so as to investigate how to improve energy efficiency. The results indicated that technological progress in eastern provinces was connected with production (Song and Wang, 2014). Huang et al. ob-

[1] China set a goal to reduce carbon intensity by 60–65% before 2030 compared with 2005

served that the impact of human capital on reducing carbon intensity varies significantly in eastern, central, and western region of China (Huang et al., 2021). Direct and indirect effects of urbanization on energy intensity from urban perspective in China are compared with consideration of the regional disparity (Lv et al., 2019). Carbon prices dynamic is revealed across Chinese regional carbon markets, showing that varying economic contexts accelerate the regional heterogeneity (Fan et al., 2019). There are some studies focused on developing countries, Akram et al. examined the heterogeneity effects of different variables on carbon emission (Akram et al., 2020). He and Lin aimed to figure out industrial heterogeneity of volatility transmitting from energy price to PPI for the period 2007–2017, but it was limited within the scope of China (He and Lin, 2019). Nowadays, studies about regional disparity and variable heterogeneity are relatively abundant, but studies about industrial heterogeneity is quite rare.

Through the above literature review, it is clear that previous studies did have done substantial work on carbon intensity, but there is still existing research gap. Carbon intensity researches involved industrial heterogeneity seems to be deficient. As we all know, the carbon reduction policies do not perfectly match all sectors. Hence, understanding the industrial carbon intensity changes and industrial heterogeneity will boost the implement of targeted measures for each sector. In addition, previous studies did not consider industries as much as possible. In this context, to take as many industries into consideration as possible, this research involves 55 industries (one industry is excluded for data limitation), in accordance with data collected from the World Input-Output Database (WIOD, 2019). In a word, this research is designed to investigate carbon intensity changes and the key influencing factors from the perspectives of globe and industry. Moreover, heterogeneity of industrial carbon intensity has also be considered, which is believed to fill research gap.

The following sections of this study are arranged as follow, methods and data sources are presented in Section 2. Section 3 conducts results analysis and discussion from various perspectives. Conclusions have been put in section 4, and based on these conclusions, this study proposes some policy implications.

2. Methods and data sources

2.1. Global carbon intensity decomposition

In order to identify the factors influencing global carbon intensity changes, this study introduces kaya identity as follow:

$$CI = \sum_i \frac{C_i}{E_i} \times \frac{E_i}{O_i} \times \frac{O_i}{O} \tag{1}$$

Where:

- ➢ CI indicates global carbon intensity.
- ➢ i=A01, A02, …, T indicates industry.[2] More detailed classification about industry is shown in Table 1.
- ➢ C_i, E_i, O_i indicate carbon emission, energy consumption, and gross economic output of industry i, respectively.
- ➢ $O = \sum_i O_i$ indicates the global total output.

The Eq. (1) can be simplified as Eq. (2), which is shown as follow:

$$CI = \sum_i \frac{C_i}{O_i} = \sum_i CE_i \times EI_i \times OS_i \tag{2}$$

In Eq. (2), CE_i refers to the ratio of carbon emission and energy consumption of industry i, which means energy mix of industry i; EI_i refers to energy consumption per unit economic output of industry i, which means energy intensity of industry i; OS_i refers to the ratio of economic output of industry i in global total output, i.e., economic structure.

On the basis of the above extended kaya identity, this paper introduces LMDI multiplicative form to explore factors influencing global carbon intensity changes in detail. Thus, changes of global carbon intensity from base year t to target year $t + 1$ has been presented in Eq. (3).

$$D = \frac{CI^{t+1}}{CI^t} = {D_{CE}}^{t,t+1} \times {D_{EI}}^{t,t+1} \times {D_{OS}}^{t,t+1} \tag{3}$$

In Eq. (3), ${D_{CE}}^{t,t+1}$represents energy mix effect, reflecting the carbon intensity changes induced by energy mix effect from base year to target year; ${D_{EI}}^{t,t+1}$denotes energy intensity effect, reflecting the carbon intensity changes induced by energy intensity effect from base year to target year; ${D_{OS}}^{t,t+1}$ represents economic structure effect, reflecting the carbon intensity changes induced by economic structure effect during the period between base year and target year. More detailed information about single-period decomposition analysis is shown in Eq. (4)-Eq. (6).[3]

$${D_{CE}}^{t,t+1} = exp(\sum_{i=1}^{N} {w_i}^{s-v} ln\frac{{CE_i}^{t+1}}{{CE_i}^{t}}) \tag{4}$$

$${D_{EI}}^{t,t+1} = exp(\sum_{i=1}^{N} {w_i}^{s-v} ln\frac{{EI_i}^{t+1}}{{EI_i}^{t}}) \tag{5}$$

$${D_{OS}}^{t,t+1} = exp(\sum_{i=1}^{N} {w_i}^{s-v} ln\frac{{OS_i}^{t+1}}{{OS_i}^{t}}) \tag{6}$$

It is acknowledged that single-period decomposition analysis is able to figure out factors influencing global carbon intensity year by year, while fails to uncover factors influencing carbon intensity changes in a certain period. In this context, multi-period decomposition analysis as an important and complementary part has come into being and palyed a valuable role. The detailed information about multi-period decomposition analysis can be seen in Eqs. (7)-(9).

$${D_{CE}}^{0,T} = \prod_{t=1}^{T} {D_{CE}}^{t,t+1} \tag{7}$$

$${D_{EI}}^{0,T} = \prod_{t=1}^{T} {D_{EI}}^{t,t+1} \tag{8}$$

$${D_{OS}}^{0,T} = \prod_{t=1}^{T} {D_{OS}}^{t,t+1} \tag{9}$$

In above equations, we can further obtain multi-period decomposition results of energy mix effect (${D_{CE}}^{0,T}$), energy intensity effect (${D_{EI}}^{0,T}$), economic structure effect (${D_{OS}}^{0,T}$).

2.2. Industrial carbon intensity decomposition

Conducting decomposition analysis of global carbon intensity enables us to identify the key factors of the carbon intensity changes. However, great differences exist among industries regarding carbon emissions, economic growth, etc. Hence, it is essential

[2] Industry U (Activities of extraterritorial organizations and bodies) is out of consideration since it is lack of data and accounts for a negligible ratio in global carbon emission.

[3] ${w_i}^{s-v} = \frac{L({C_i}^t/C^t, {C_i}^{t+1}/C^{t+1})}{\sum_{i=1}^{N} L({C_i}^t/C^t, {C_i}^{t+1}/C^{t+1})}$ $L(x,y) = \{ \begin{matrix} \frac{(x-y)}{(lnx-lny)} & x \neq y \\ x \text{ or } y & x = y \end{matrix}$ $\langle /END \rangle$carbon emission in million tons (Mt) and gross output in billion dollars (Bd)

Table 1
Detailed industrial classification.

Code	Detail	Code	Detail
A01	Crop and animal production, hunting and related service activities	**G46**	Wholesale trade, except of motor vehicles and motorcycles
A02	Forestry and logging	**G47**	Retail trade, except of motor vehicles and motorcycles
A03	Fishing and aquaculture	**H49**	Land transport and transport via pipelines
B	Mining and Quarrying	**H50**	Water transport
C10-C12	Manufacture of food products, beverages and tobacco products	**H51**	Air transport
C13-C15	Manufacture of textiles, wearing apparel and leather products	**H52**	Warehousing and support activities for transportation
C16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	**H53**	Postal and courier activities
C17	Manufacture of paper and paper products	**I**	Accommodation and food service activities
C18	Printing and reproduction of recorded media	**J58**	Publishing activities
C19	Manufacture of coke and refined petroleum products	**J59-J60**	Motion picture, video and television program production, sound recording and music publishing activities; programming and broadcasting activities
C20	Manufacture of chemicals and chemical products	**J61**	Telecommunications
C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	**J62-J63**	Computer programming, consultancy and related activities; information service activities
C22	Manufacture of rubber and plastic products	**K64**	Financial service activities, except insurance and pension funding
C23	Manufacture of other non-metallic mineral products	**K65**	Insurance, reinsurance and pension funding, except compulsory social security
C24	Manufacture of basic metals	**K66**	Activities auxiliary to financial services and insurance activities
C25	Manufacture of fabricated metal products, except machinery and equipment	**L68**	Real estate activities
C26	Manufacture of computer, electronic and optical products	**M69-M70**	Legal and accounting activities; activities of head offices; management consultancy activities
C27	Manufacture of electrical equipment	**M71**	Architectural and engineering activities; technical testing and analysis
C28	Manufacture of machinery and equipment n.e.c.	**M72**	Scientific research and development
C29	Manufacture of motor vehicles, trailers and semi-trailers	**M73**	Advertising and market research
C30	Manufacture of other transport equipment	**M74-M75**	Other professional, scientific and technical activities; veterinary activities
C31-C32	Manufacture of furniture; other manufacturing	**N**	Administrative and support service activities
C33	Repair and installation of machinery and equipment	**O84**	Public administration and defense; compulsory social security
D35	Electricity, gas, steam and air conditioning supply	**P85**	Education
E36	Water collection, treatment and supply	**Q**	Human health and social work activities
E37-E39	Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services	**R-S**	Other service activities
F	Construction	**T**	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use
G45	Wholesale and retail trade and repair of motor vehicles and motorcycles		

to further investigate key factors of the industrial carbon intensity changes. LMDI additive decomposition methods and extended kaya identity are combined,

$$CI_i = \frac{C_i}{E_i} \times \frac{E_i}{O_i} = CE_i \times EI_i \tag{10}$$

According to extended kaya identity, industrial carbon intensity is decomposed into two factors: energy mix (CE_i) and energy intensity (EI_i). Then we continue to investigate carbon intensity changes from base year to target year of industry i.

$$\Delta CI_i = {CI_i}^{t+1} - {CI_i}^{t} = \Delta {CI_i}^{CE} + \Delta {CI_i}^{EI} \tag{11}$$

$$\Delta {CI_i}^{CE} = \sum\nolimits^{L} ({CI_i}^{t+1},\ {CI_i}^{t}) \ \times \ \ln\left(\frac{{CE_i}^{t+1}}{{CE_i}^{t}}\right) \tag{12}$$

$$\Delta {CI_i}^{EI} = \sum\nolimits^{L} ({CI_i}^{t+1},\ {CI_i}^{t}) \ \times \ \ln\left(\frac{{EI_i}^{t+1}}{{EI_i}^{t}}\right) \tag{13}$$

$$\mathrm{L}\left(CI^{t+1},\ CI^{t}\right) = \begin{cases} \frac{CI^{t+1}-CI^{t}}{\ln\left(CI^{t+1}/CI^{t}\right)} & \left(CI^{t+1}CI^{t} \neq 0\right) \\ CI^{t+1} \ or \ CI^{t} & \left(CI^{t+1} = CI^{t}\right) \\ 0 & \left(CI^{t+1}CI^{t} = 0\right) \end{cases} \tag{14}$$

Where $\Delta {CI_i}^{CE}$ and $\Delta {CI_i}^{EI}$ respectively denote energy mix effect and energy intensity effect. Moreover, energy mix effect denotes industrial carbon intensity changes caused by energy mix adjustment; energy intensity effect denotes industrial carbon intensity changes caused by energy efficiency improvement. We mainly explore the factors of industrial carbon intensity changes from two perspectives: structure adjustment and technological improvement.

2.3. Data sources

This study aims to observe how global and industrial carbon intensity change, and what effects drive most on global and industrial carbon intensity change. Data of carbon emission, industrial-by-industrial gross output, and emission relevant energy use is collected from the World Input-Output Database (WIOD, 2019). The database only updated data of industrial-by-industrial to 2014. Moreover, the period 2000–2014 covers 2008 global financial crisis, which is able to uncover carbon emission before and after financial crisis. Consequently, this study explores carbon intensity changes in 2000–2014. To avoid the impact of inflation, the gross economic output is adjusted to the level in 2010. In addition, 55 industries from WIOD have been taken into consideration, while industry U is excluded due to the lack of data and negligible ration total carbon emission.

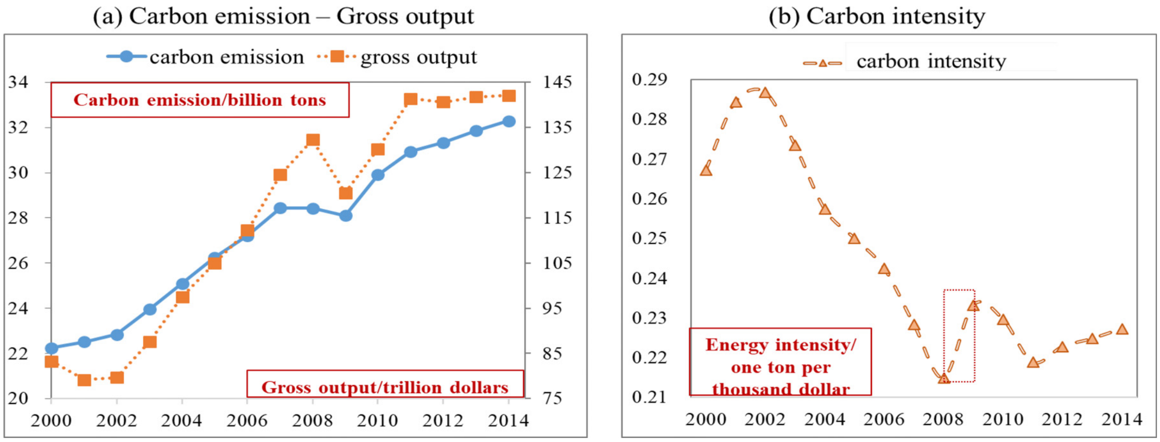

Fig. 1. Changes of carbon emission, gross output, and carbon intensity at global level.

3. Results and discussion

3.1. Carbon intensity development observation

3.1.1. Carbon intensity changes at global level

Global carbon emission and gross economic output changes are presented in Fig. 1-(a), and Fig. 1-(b) demonstrates the global carbon intensity changes. Both carbon emission and gross economic output showed an increasing trend between 2000 and 2014. To be more specific, global carbon emission increased from 22.25 billion tons to 32.30 billion tons, with an overall increase rate of 45.17% in the whole period. Particularly, due to the shock of the global financial crisis, global carbon emission decreased by 1.19% in 2007–2009. However, global carbon emission rebounded violently in 2009–2010, which reached a far higher increase rate of 6.4%. Moreover, it is great to find that increase rate of global carbon emission slowed down after the 2008 global financial crisis, which was only 1.94% in 2010–2014, nearly half of that in 2000–2007 (3.58%). For global economic output, it can be classified into four phases: slight reduction during 2000–2002, drastically increase between 2002 and 2008, sharp fluctuation during 2008–2011, and constant trend between 2011 and 2014. In reality, global economy rose rapidly before the financial crisis, especially in 2003–2004 where global output increased by 11.34%, reaching the peak. Unfortunately, shocked by financial crisis, global output initially reduced and then rebounded drastically in 2008–2011. In addition, gross output seems to be more vulnerable to global financial crisis than carbon emission, causing itself fluctuates more drastically than carbon emission. Compared with continuous increasing of carbon emission, it is bad for global output to hold still.

Carbon intensity, the ratio of carbon emission and gross output, has nearly opposite changes with global carbon emission and gross output. On the whole, global carbon intensity decreased from 0.2672 ton per thousand dollars (tpt) in 2000 to 0.2273tpt in 2014, with an overall decrease rate of 14.94%. Specifically speaking, its changes can also be classified into four phases: rapid increase during 2000–2002, the dramatic reduction between 2002 and 2008, a reversed-V shape trend during the period 2008–2011, and slightly increase over 2011–2014. Confronting the financial crisis, carbon intensity drastically fluctuated, which increased by 8.53% in the period 2008–2009. Furthermore, global carbon intensity gradually increased recently, meaning that economic growth is accompanied by more carbon emissions. Countries all over the world shall pay attention to the increase of carbon intensity since it represents the deterioration of relationship between environmental issues and economic growth.

3.1.2. Carbon intensity changes at industrial level

Great heterogeneity exists among industries for two aspects: initial carbon emission and carbon emission changes Table 2. Firstly, industrial D35 owns the largest initial carbon emission (9207 Mt), while industry T has the lowest initial value (0.16 Mt). Secondly, nearly 36% industries achieved carbon reduction in the whole period. Moreover, for industries with carbon emission increase, only 8 industries increased over 100 Mt. Moreover, industry D35, industry C23, and industry C24, the top three emitters regarding to carbon increase, got an increase of carbon emission of 5306 Mt, 1465 Mt, and 1101 Mt, respectively. As a result, it is of great importance to formulate and implement targeted carbon reduction measures according to specific situations of all industries.

Similar to the overall carbon emission, heterogeneity also exists among gross industrial output. In general, the gross output for all industrials increased in 2000–2014 except for industry C18, which decreases by 13 billion dollars. Nearly 44% of industries got gross output increased over 1000 billion dollars for gross economic output increase. In addition, concerning gross output increase, the top three are industry F, industry B, and industry L68, which increased by 5049 billion dollars, 3286 billion dollars, and 2936 billion dollars, respectively. It should also note that there is a great gap among industries for output amplification. In addition, industry with the largest increase rate of carbon emission is not that industry with the largest increase rate of gross out and vice versa. In order to investigate industrial carbon intensity changes, we choose several typical industries according to carbon emission performance and gross output performance.

According to previous discussion about industrial carbon emission and gross output, we decide to use top three industries data according to carbon increase, carbon reduction, respectively, and top six industries are selected according to the gross economic output increase. The carbon intensity changes of the remaining industries are listed in Table 1, Appendix A.

Fig. 2 shows the carbon intensity changes of specific industries chosen in accordance with carbon increase and carbon reduction, respectively. As shown in Fig. 2-(a), industry D35 ranked the first for initial carbon intensity, far higher than the remaining industries. Besides, though it successively achieved carbon intensity reduction of approximate 25%, its carbon intensity was still high and needed to get further improved. Industry C23 and industry C24 shared a similar but gentler tend with industry D35. Moreover, all three chosen industries with carbon intensity increase showed an inversed-V shape in 2008–2011, which could be caused by the 2008 global financial crisis.

As demonstrated in Fig. 2-(b), industry C17, industry C13-C15, and industry G45 all leaded carbon intensity drop, with a reduc-

Table 2
Carbon emission V.S. gross output at industrial level[5](WIOD, 2019).

Industry	Carbon emission			Gross output			Industry	Carbon emission			Gross output		
	2000	2014	2000–2014	2000	2014	2000–2014		2000	2014	2000–2014	2000	2014	2000–2014
A01	519	599	79	2603	4165	1562	**G46**	230	214	−15	4255	6906	2650
A02	45	74	29	224	317	93	**G47**	254	221	−33	3223	4467	1244
A03	35	43	8	183	364	181	**H49**	890	1185	295	2237	3553	1316
B	762	1200	438	1739	5025	3286	**H50**	610	694	84	383	600	217
C10-C12	280	335	55	3463	6029	2566	**H51**	813	800	−13	468	683	215
C13-C15	152	129	−24	1741	2373	632	**H52**	90	125	36	732	1439	706
C16	48	60	11	481	851	370	**H53**	23	23	0	245	343	99
C17	180	161	−19	742	898	156	**I**	182	203	21	2220	3395	1175
C18	34	16	−18	464	451	−13	**J58**	3	2	−1	587	601	14
C19	765	876	110	1271	3371	2101	**J59_J60**	6	4	−2	508	658	150
C20	973	1432	459	1933	3746	1813	**J61**	23	19	−5	1525	2139	614
C21	11	11	1	588	1120	532	**J62_J63**	33	34	1	969	1884	915
C22	346	672	326	993	1559	566	**K64**	46	47	1	2592	4096	1505
C23	1453	2918	1465	865	1712	847	**K65**	27	23	−5	1202	1942	740
C24	1648	2749	1101	1611	3924	2313	**K66**	11	9	−2	634	778	144
C25	76	117	41	1367	2206	839	**L68**	69	62	−7	4883	7823	2939
C26	48	37	−10	2328	3570	1243	**M69_M70**	57	78	21	1507	3179	1672
C27	36	47	10	1033	2081	1048	**M71**	28	31	3	670	1030	361
C28	87	96	10	1635	3147	1512	**M72**	21	29	8	406	725	320
C29	66	57	−9	2280	4010	1729	**M73**	11	10	−1	407	512	105
C30	31	32	0	573	1308	736	**M74_M75**	21	34	13	507	1021	515
C31_C32	177	241	64	919	1066	147	**N**	145	133	−13	2249	3300	1051
C33	8	7	−1	203	296	93	**O84**	518	532	14	5247	7853	2605
D35	9207	14,512	5306	2185	4567	2382	**P85**	137	182	44	1790	3278	1488
E36	44	37	−7	215	322	107	**Q**	206	275	69	3159	5891	2732
E37-E39	229	228	−1	340	510	170	**R_S**	167	210	43	1915	3017	1102
F	313	385	72	5529	10,578	5049	**T**	0.16	0.18	0.02	145	179	34
G45	54	49	−5	1090	1253	163							

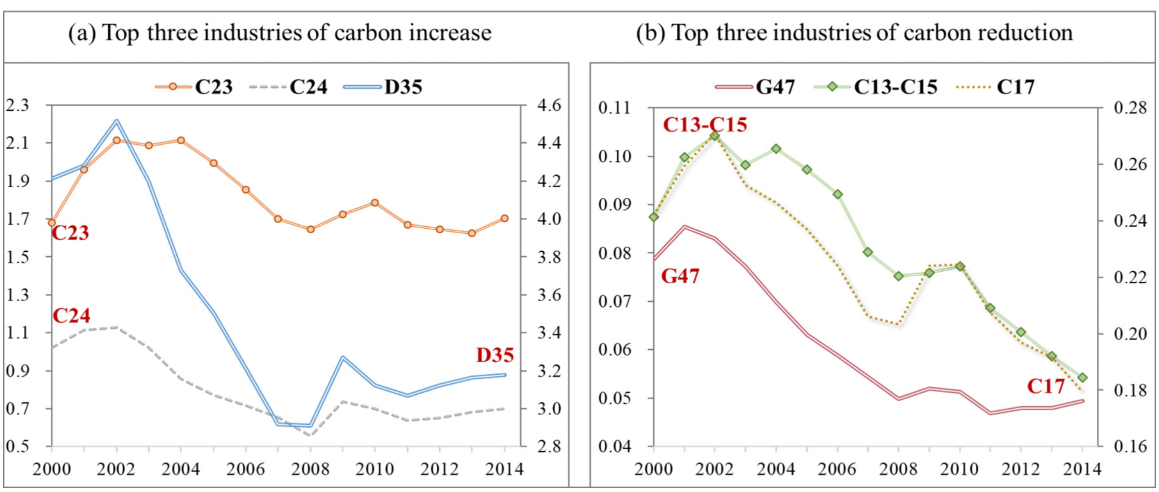

Fig. 2. Carbon intensity changes in 2000–2014 of chosen industries in accordance with carbon emission change.

tion of 0.0629 tpt, 0.0332 tpt, and 0.0293 tpt, respectively for the period 2000–2014. In addition, it is noticeable that all three industries in Fig. 2-(a) have similar changes while all three industries in Fig. 2-(b) showed just a minor difference. Unlike the remaining four industries, industry C17 and industry C13-C15 tended to continue reducing carbon intensity. What's more, it is worthy to notice that industry C17 and industry G47 showed an inversed-U shape during 2008–2011, which indicates that industries with minor initial carbon intensity will give a slower and minor response to external contingency.

Fig. 3 shows carbon intensity changes of specific industries chosen in accordance with gross economic output increase. It is noticeable that all six industries have successfully reduced carbon intensity for the study period. Among all industries, industry B, which has the largest initial carbon intensity, reduced the most, with a reduction of carbon intensity by 0.1993 tpt, followed by industry O84, which reduced by 0.0310 tpt. The six industries tended to continue reducing carbon intensity, which is more significant for the industries with large initial value, like industry B and industry O84. Interestingly, industries with large initial carbon intensity have been more severely impacted by 2008 global financial crisis, and the carbon intensity increased immediately. However, carbon intensity of all industries sees a rebound after global financial crisis (see Table 1 in Appendix A).

3.2. Global carbon intensity decomposition analysis

3.2.1. Single-period decomposition analysis

For the sake of reducing carbon intensity effectively, it is indispensable to identify the influencing factors and the mechanism of carbon intensity changes. Here we present carbon intensity de-

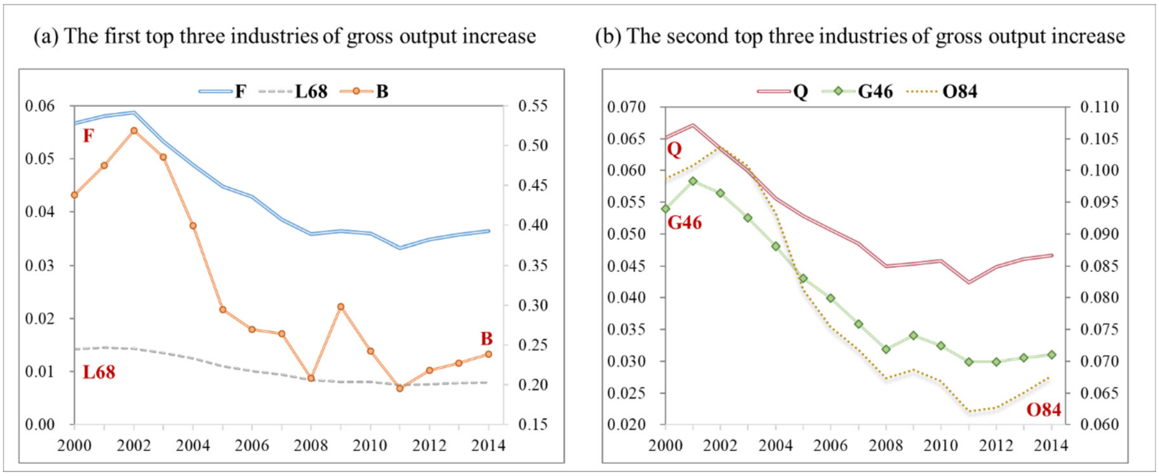

Fig. 3. Carbon intensity changes in 2000–2014 of chosen industries in accordance with gross output change.[4]

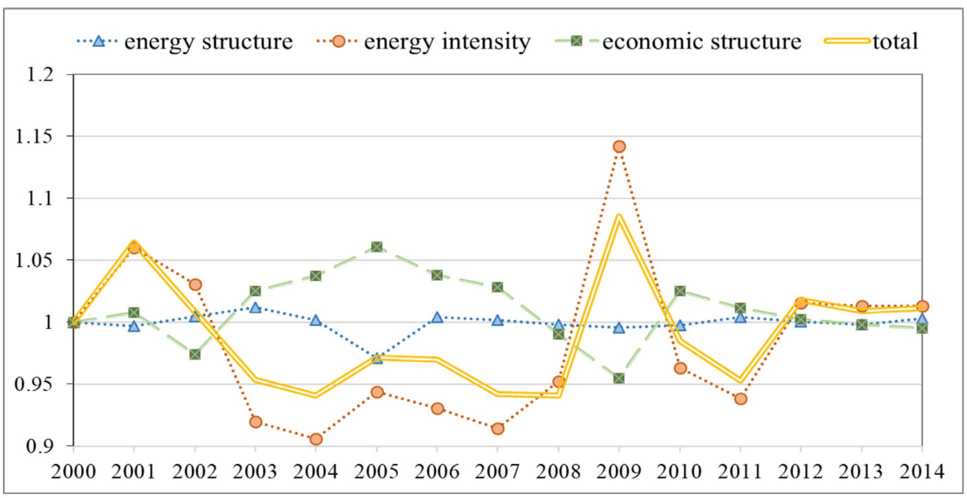

Fig. 4. Single-period decomposition results of carbon intensity at global level.

composition results in single-period Fig. 4, and the detailed information about decomposition is shown in Table 1, Appendix B.

Obviously, economic structure effect is a brilliant form promoting the increase of global carbon intensity, with an average annual growth rate highly reaching 8.47%. Energy mix effect follows the economic structure effect, makes itself the second promotor to global carbon intensity increase. However, the impact of energy mix effect on global carbon intensity tends to be stable and negligible since 2006. Reversely, energy intensity effect remarkably promotes carbon intensity decrease, which is in line with the studies of Chen et al.(Chen et al., 2019), Zhang et al.(Zhang et al., 2019), and Wang and Wang(Wang and Wang, 2020b). In addition, it is not hard to find that carbon intensity shares a similar trend with the impact of energy intensity on carbon intensity, while opposite trend with economic structure. In this context, the adjustment and optimization of economic structure and energy mix should be put on agenda, and it is necessary to carry on improvement of energy intensity.

3.2.2. Multi-period decomposition analysis

The multi-period decomposition results of carbon intensity at global level are presented in Fig. 5. Overall, the total carbon intensity sees a remarkable decline, and the cumulative contribution reaches the largest level in 2008. As for the energy mix effect, it shows a relative minor impact on carbon intensity all the time. It cumulatively promotes carbon intensity decline, with an average annual growth rate of −11.56%. Economic structure effect makes itself the primary contributor to carbon intensity increase for most time, particular for the period of 2002–2008. On the contrary, energy intensity effect drives carbon intensity to decrease, especially between 2002 and 2008. Furthermore, the impacts of energy intensity and economic structure changes on carbon intensity fluctuate during 2007–2011 since got shocked by 2008 financial crisis, the energy mix effect, on the contrary, tends to stay still. The positive impact of energy intensity and energy mix on carbon intensity decrease outstrips economic structure effect. Hence, total carbon intensity achieves a decline for the overall trend.

3.3. Industrial carbon intensity decomposition analysis

After decomposition analysis of global carbon intensity, we analyze the carbon intensity decomposition results at industrial level. Since there are 55 industries, it is necessary to classify them firstly. Hence, we classify these 55 industries according to initial carbon intensity and carbon intensity growth rate (see Figs. 1 and 2 in Appendix C). Firstly, based on initial carbon intensity and carbon intensity growth rate, 55 industries are classified into three categories: industries with positive growth rate, industries with large initial carbon intensity, and the remaining industries. Secondly, the remaining industries are reclassified according to carbon intensity growth rate since most of them with relatively low initial carbon intensity value.

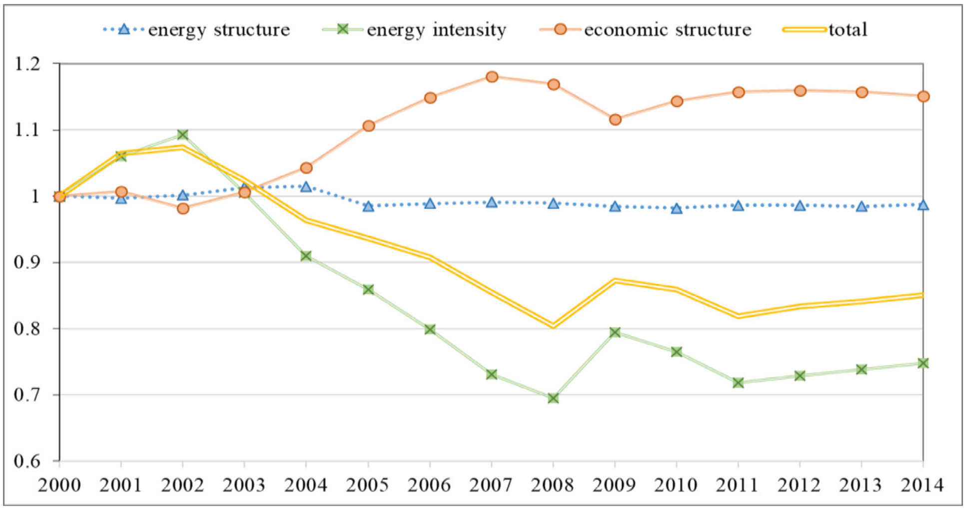

Fig. 5. Multi-period decomposition results of carbon intensity at global level.

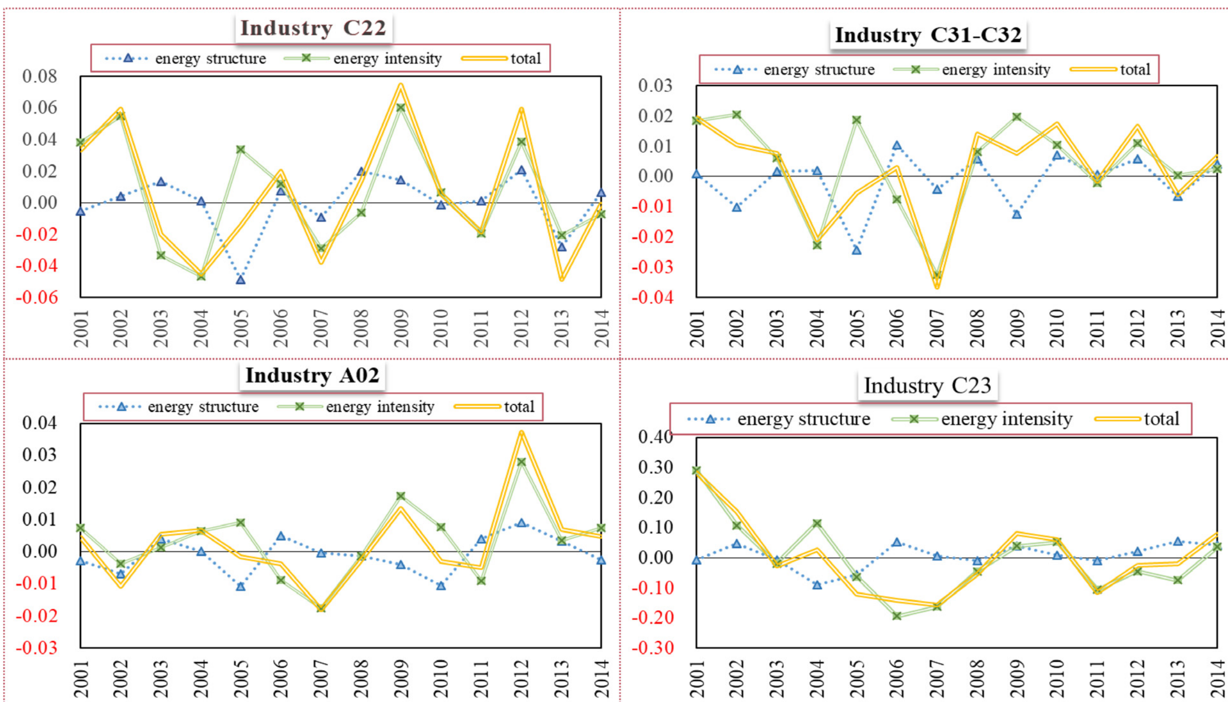

Fig. 6. Carbon intensity decomposition analysis of industries with positive growth rate.

3.3.1. Carbon intensity decomposition analysis of particular industries

As shown in Fig. 6, only four industries get carbon intensity increase, accounting for nearly 7% for total industries. Amongst these industries, the increase of carbon intensity is relatively limited, with industries C22 increased by 23.77% to reach the peak, industry C23 increased by 1.48% to get to the bottom. Regarding the factors influencing industrial carbon intensity changes, energy intensity effect and energy mix effect have distinct impacts on different industries, e.g., they exert opposite effects on industry C31-C32 and industry C23. In addition, energy intensity effect stands out in increasing carbon intensity for industries with positive carbon intensity growth rate.

For industries with large initial carbon intensity Fig. 7, carbon intensity tended to decrease drastically, for instance, industry C19 decreased carbon intensity by 56.88% for the period 2000–2014. Energy intensity effect always promotes the industrial carbon intensity to decrease. It should be noted that energy intensity effect is regarded as the largest contributor to carbon intensity decrease. Energy mix effect could have opposite impacts on carbon intensity decrease in different industries. Overall, the impact of energy mix effect on carbon intensity change is far less than energy intensity effect except industry H50, where energy intensity (−14.16%) and energy mix effect (−13.26%) exert influence on overall emission intensity change (−27.42%).

There are just two industries whose carbon intensity growth rate is larger than zero and smaller than or equal to 10% (see Fig. 8). For these two industries, energy mix effect has a positive impact on carbon intensity decrease while energy intensity puts a negative impact. Moreover, the impact of energy mix effect on industrial carbon intensity change is slightly stronger than that of energy intensity.

Fig. 7. Carbon intensity decomposition analysis of industries with large initial carbon intensity (initial carbon intensity ≥0.5tpt)3.3.2 Carbon intensity decomposition analysis of remaining industries.

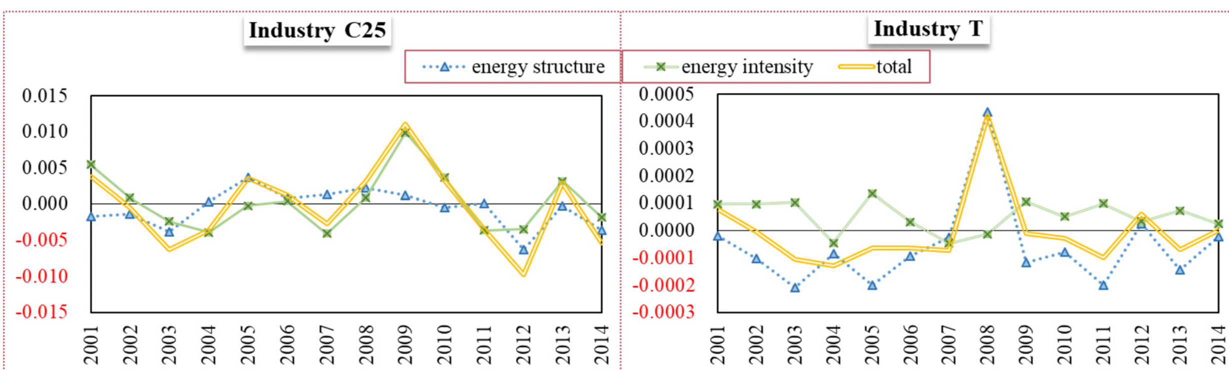

Fig. 8. Carbon intensity decomposition analysis of industries (0≤growth rate≤10%).

There are just two industries whose carbon intensity growth rate is larger than 10% and smaller than or equal to 20% (see Fig. 9), both energy intensity effect and energy mix effect lead to industrial carbon intensity decrease. However, the effect of energy mix is far weaker than energy intensity, particular in industry M74-M75 where energy intensity effect nearly 30 times stronger than energy mix effect.

As presented in Fig. 10, there are 12 industries whose carbon intensity growth rate ranges from 20% to 30%, approximately accounting for one fifth in total industries. Amongst these industries, industries whose carbon intensity growth rate surpass 25% accounts for 75%. Energy intensity accelerates carbon intensity increase for these industries (except industry P85), and it also is the foremost driver (except industry C17). Energy mix also promotes carbon intensity decrease (except industry H53 and industry Q). It is worth noting that energy mix has a more significant effect on the decrease of carbon intensity than energy intensity in industry C17 and industry P85).

There are ten industries with a carbon intensity growth rate with the range 40% to 50% (see Fig. 12). Amongst them, industry C26 ranks the first in carbon intensity growth rate, which is −48.99%. For factors influencing carbon intensity change, both the energy intensity and energy mix accelerate carbon intensity decrease for all these industries (except energy mix of industry B). More generally, energy intensity is a great booster to decrease carbon intensity for almost industries. Moreover, for industry G46, industry J61, and industry C21, energy mix has a stronger effect on carbon intensity change than energy intensity effect. And the effect of energy mix on carbon intensity change is in accordance with energy intensity for industry E36.

There are four industries with carbon intensity growth rate larger than 50% and smaller than or equal to 60% (see Fig. 13). Both energy intensity and energy mix significantly accelerate carbon intensity decrease. In addition, energy intensity exerts a slightly stronger impact on carbon intensity decrease than energy mix.

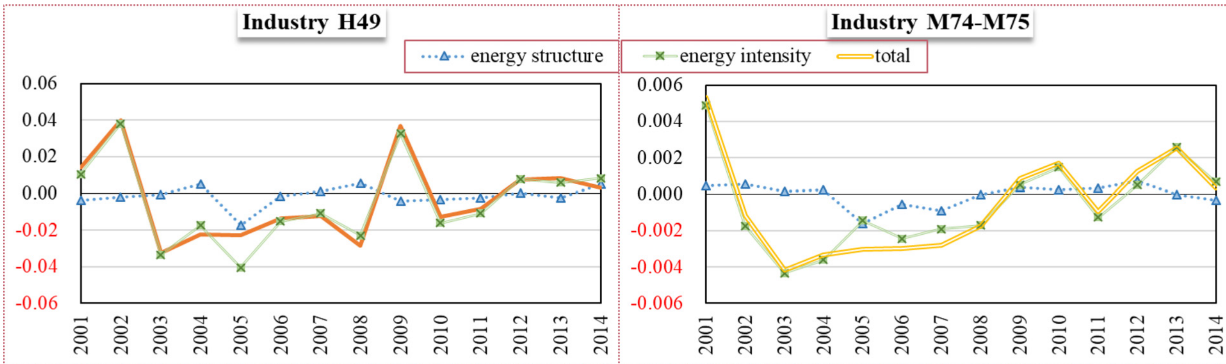

Fig. 9. Carbon intensity decomposition analysis of industries (10%<growth rate≤20%).

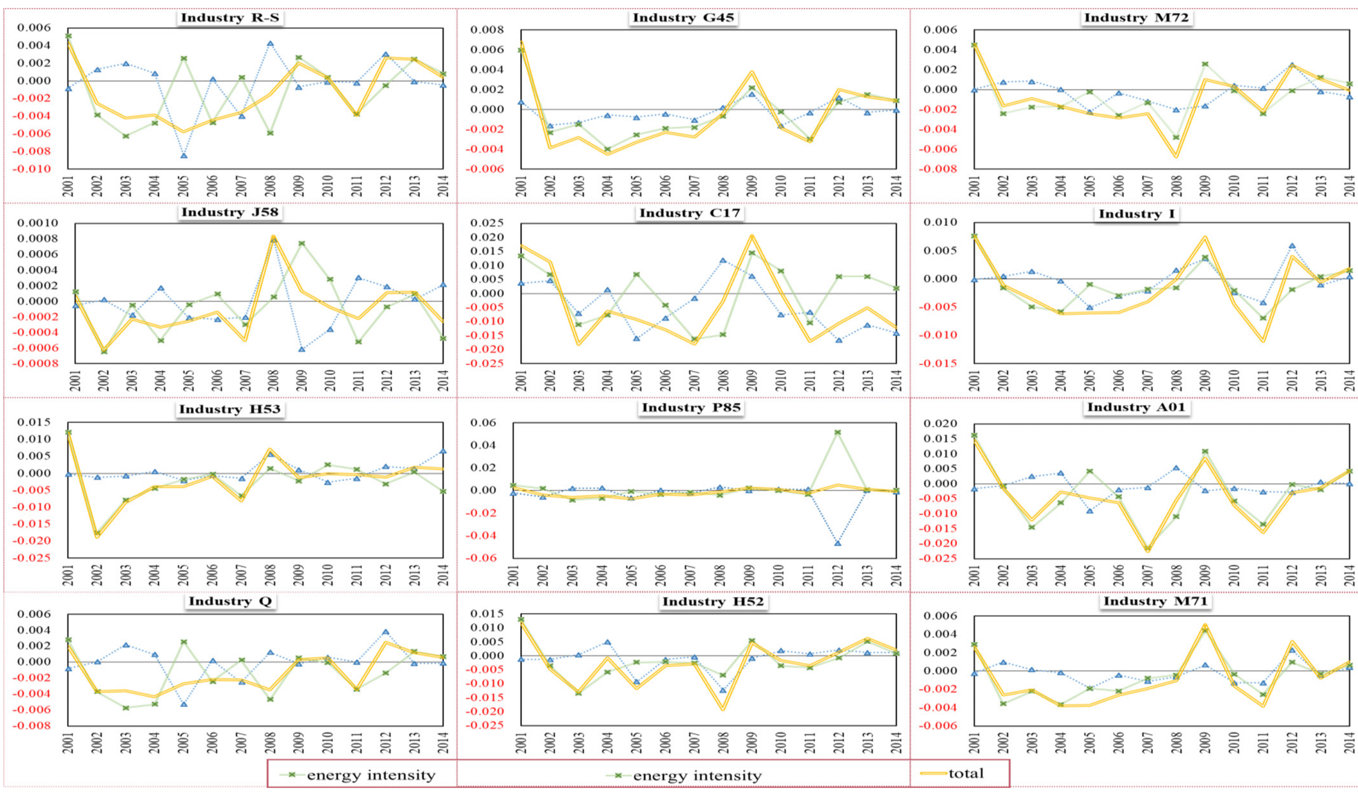

Fig. 10. Carbon intensity decomposition analysis of industries (20%<growth rate≤30%)There are fourteen industries with carbon intensity growth rate larger than 30% and smaller than or equal to 40% (see Fig. 11). Industries in this carbon intensity range has the largest amount, accounting for more than 25% in total industries. To be more specific, there are ten industries with carbon intensity growth rate in the range of 35% and 40%. Energy intensity significantly accelerates carbon intensity decrease for all industries except industry O84, where energy intensity presents a negative impact on carbon intensity decrease. As for the energy mix effect, most industries see a carbon intensity decrease except the industry C16 and industry K66. As the discussed industries, energy mix has a slightly weaker effect on carbon intensity change than the energy intensity. However, industry C33 is an exception, whose energy intensity decreases by 38.62% for the period of 2000–2014, on the other hand, energy mix (−21.15%) has a slightly stronger effect on energy intensity (−17.47%). In addition, energy intensity (48.46%) has a negative impact while energy mix (−79.86%) has a positive and more significant impact on carbon intensity change for industry O84, whose carbon intensity decreases by 31.4% during the whole period.

This study is conducted to figure out what position global carbon intensity is in and how carbon intensity changes in a current and future situations. Moreover, this study focuses on factors influencing carbon intensity both at global and industrial level. In this context, we learn from the experience of 2008 global financial crisis and try to shed a light on carbon control after the COVID-19 pandemic. Here are some key conclusions:

- ➢ Though both global carbon emission and gross output increased in 2000–2014, gross output (70.68%) owns a higher growth rate than carbon emission (45.17%). However, gross output is likely to hold still, while carbon emission tends to increase continuously, which is bad for coordinating the relationship between environmental issues and economic development.
- ➢ For industrial carbon emission and gross output, these is great heterogeneity among industries. All industries increased output except industry C18. In addition, what a great difference on output increase, with industry B increased by 3286 billion dollars, industry J58 only increased by 14 billion dollars. Similar things happen in industrial carbon emission.
- ➢ For global carbon intensity, though it achieved reduction in the whole period, it cannot relax since global carbon intensity is likely to continuously increase in the foreseeable future. Moreover, the outbreak of financial crisis caused a se-

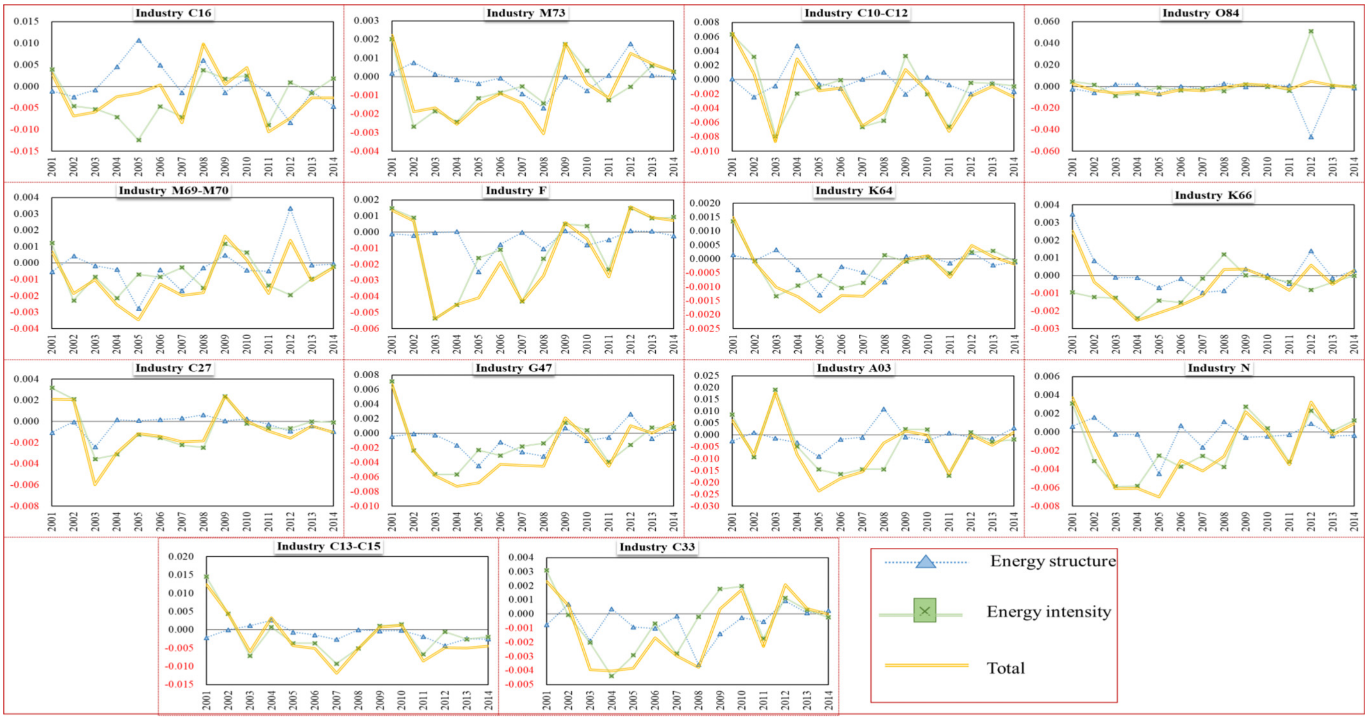

Fig. 11. Carbon intensity decomposition analysis of industries (30%<growth rate≤40%).

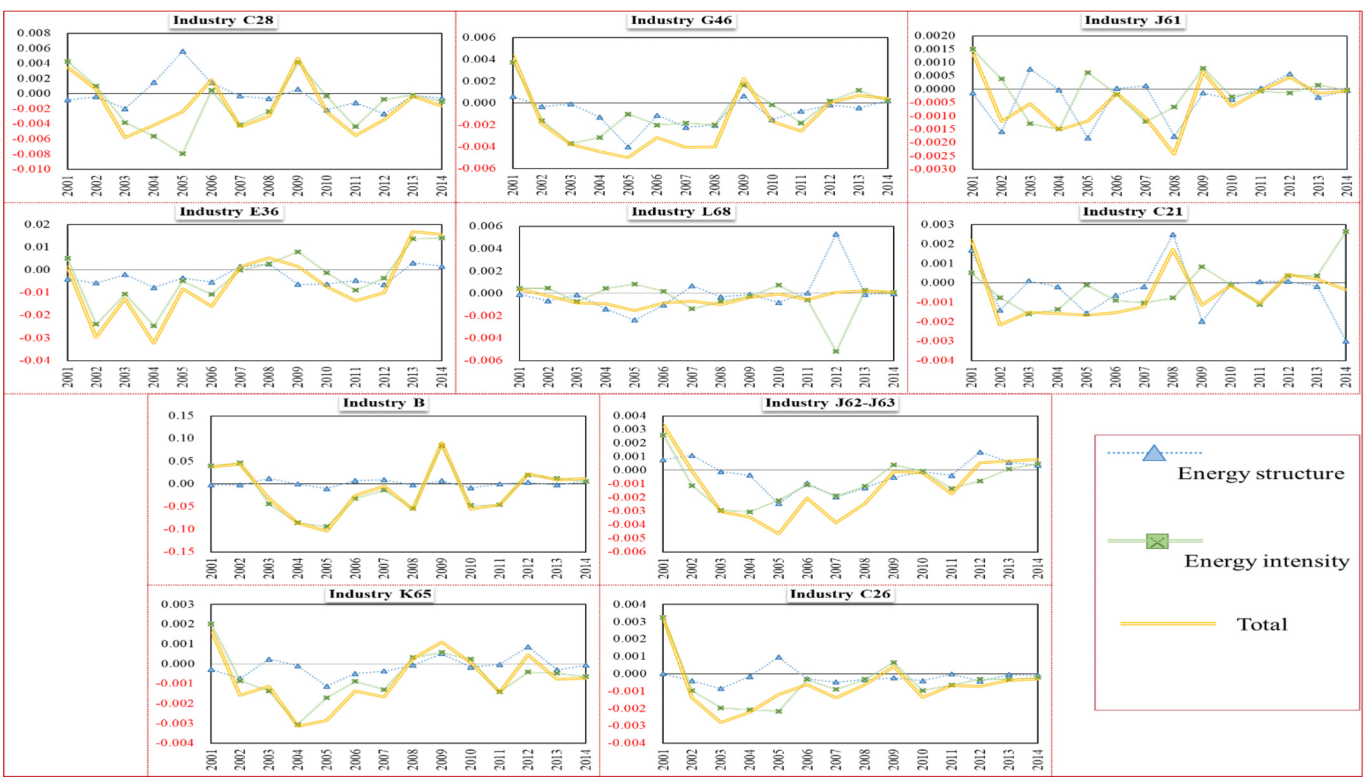

Fig. 12. Carbon intensity decomposition analysis of industries (40%<growth rate≤50%).

rious impact on global carbon intensity, making it spear a converted-V shape.

➢ For industrial carbon intensity, half of them indeed decreased, like industry D35 which decreased the most. However, it is a fact that carbon intensity of most industries is still high, like industry D35 whose value is still as high as 3.1776 in 2014. Industries with a decrease rate of 30%–40% account for the largest part in industries with carbon intensity decrease, followed by rate of 20%–30% and 40%–50%. The above means industries, especially industries with carbon intensity decrease need to work harder to further reduce carbon intensity.

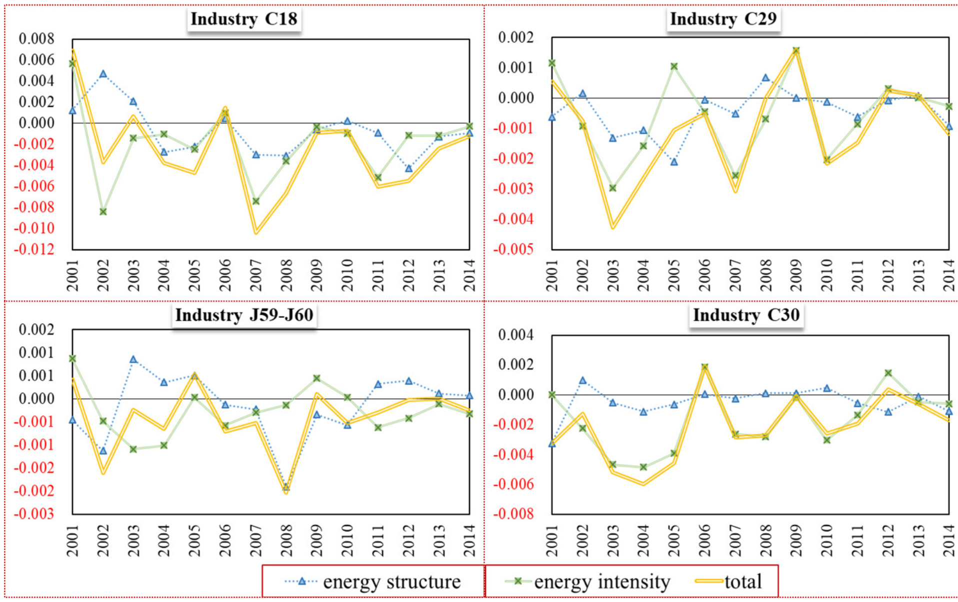

Fig. 13. Carbon intensity decomposition analysis of industries (50%<growth rate≤60%) Conclusions and policy implications.

- ➢ Regarding to global carbon intensity decomposition analysis, economic structure and energy intensity exert negative and positive impact on global carbon intensity decrease, respective. Energy mix has a positive but minor impact. Besides, energy intensity effect has a much stronger impact on carbon intensity than the economic structure effect, which explains the similar trend of energy intensity to global carbon intensity. Furthermore, both economic structure and energy intensity response drastically to 2008 global financial crisis, presenting a V-shape and a converted-V shape, respective.
- ➢ Regarding to global carbon intensity decomposition analysis, heterogeneity exists. Energy intensity significantly drives carbon intensity decrease for almost industries and makes itself the largest promotor. As for energy mix effect, its impact on carbon intensity decrease varies among industries, for instance, positive in industry A01 while negative in industry B. In addition, energy intensity has a comparatively stronger effect on industrial carbon intensity than energy mix to some extent.

According to above conclusions, it is possible to propose some scientific and practical policy implications for carbon intensity reduction whether on global or industrial level. Here are some policy implications as follow:

- ➢ More efforts shall be made to reduce global carbon emission. The reason why global carbon intensity continuous increasing is the increasing carbon emission. Countries all over the world should work together to formulate and implement carbon reduction measures in accordance with their reality.
- ➢ Accelerating innovation and flow of technologies. Inmoving and enhancing carbon reduction or energy-saving technologies is directly conducive to carbon intensity decrease. Meanwhile, countries with less improved technologies should committee to work with advanced countries, and introduce advanced technologies from these countries.
- ➢ Industries with large carbon intensity increase should act quickly to curb carbon intensity, since industries with large carbon intensity increase usually have far worse situations, like industry H51. For similar reason, industries with larger carbon intensity decrease should pay more attention to reduce carbon emission without hindering economic development, like industry D35.
- ➢ Energy intensity shall be furthermore improved. For both global and industrial carbon intensity, energy intensity is usually the primary contributor to carbon intensity decrease. For future work, it is important to apply more renewable clean or low-carbon energy instead of carbon-intensive fossil fuel. Besides, innovating relevant technologies shall be put on agenda.
- ➢ Whether improving energy intensity or optimize energy structure should be in accordance with industrial reality. For different industries, the impact of energy intensity and energy structure on industrial carbon intensity vary. Hence, formulating and implementing targeted measures according to industrial reality can be paid off effectively.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Table A1.

Table A1
Carbon intensity at industrial level.

Industry	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2000–2014
A01	0.1996	0.2141	0.2126	0.2005	0.1978	0.1931	0.1868	0.1641	0.1586	0.1672	0.1599	0.1437	0.1407	0.1394	0.1438	**−0.0558**
A02	0.1983	0.2028	0.1922	0.1976	0.2043	0.2028	0.1989	0.1810	0.1784	0.1918	0.1889	0.1839	0.2210	0.2279	0.2327	**0.0344**
A03	0.1898	0.1959	0.1875	0.2053	0.1972	0.1736	0.1552	0.1398	0.1364	0.1381	0.1381	0.1217	0.1220	0.1176	0.1188	**−0.0710**
B	0.4381	0.4751	0.5186	0.4859	0.3993	0.2949	0.2696	0.2647	0.2081	0.2986	0.2427	0.1959	0.2182	0.2271	0.2388	**−0.1993**
C10-C12	0.0809	0.0874	0.0882	0.0795	0.0825	0.0809	0.0797	0.0732	0.0687	0.0701	0.0684	0.0612	0.0589	0.0580	0.0555	**−0.0253**
C13-C15	0.0874	0.0998	0.1042	0.0982	0.1016	0.0972	0.0922	0.0802	0.0752	0.0759	0.0772	0.0686	0.0637	0.0587	0.0542	**−0.0332**
C16	0.1000	0.1030	0.0961	0.0902	0.0878	0.0862	0.0866	0.0783	0.0882	0.0887	0.0930	0.0825	0.0752	0.0726	0.0700	**−0.0301**
C17	0.2424	0.2595	0.2708	0.2526	0.2463	0.2371	0.2241	0.2062	0.2034	0.2241	0.2245	0.2075	0.1968	0.1917	0.1795	**−0.0629**
C18	0.0733	0.0802	0.0765	0.0771	0.0734	0.0687	0.0701	0.0597	0.0531	0.0522	0.0514	0.0454	0.0399	0.0375	0.0363	**−0.0370**
C19	0.6024	0.6957	0.7023	0.6277	0.5206	0.3822	0.3432	0.3127	0.2806	0.3577	0.3014	0.2476	0.2398	0.2477	0.2597	**−0.3426**
C20	0.5034	0.5438	0.5380	0.4926	0.4850	0.4534	0.4376	0.4047	0.3719	0.4331	0.4173	0.3793	0.3714	0.3744	0.3824	**−0.1210**
C21	0.0179	0.0201	0.0180	0.0165	0.0149	0.0132	0.0117	0.0104	0.0121	0.0110	0.0108	0.0098	0.0102	0.0104	0.0101	**−0.0079**
C22	0.3485	0.3817	0.4409	0.4212	0.3762	0.3618	0.3817	0.3440	0.3581	0.4330	0.4386	0.4205	0.4800	0.4318	0.4313	**0.0828**
C23	1.6795	1.9616	2.1159	2.0886	2.1153	1.9955	1.8555	1.6989	1.6449	1.7248	1.7852	1.6692	1.6451	1.6259	1.7044	**0.0249**
C24	1.0228	1.1136	1.1289	1.0227	0.8570	0.7724	0.7166	0.6554	0.5546	0.7360	0.6993	0.6396	0.6501	0.6817	0.7006	**−0.3222**
C25	0.0557	0.0595	0.0590	0.0527	0.0492	0.0527	0.0539	0.0512	0.0543	0.0655	0.0688	0.0652	0.0555	0.0584	0.0530	**−0.0027**
C26	0.0205	0.0238	0.0224	0.0196	0.0173	0.0161	0.0155	0.0141	0.0135	0.0139	0.0125	0.0119	0.0111	0.0108	0.0105	**−0.0100**
C27	0.0350	0.0371	0.0392	0.0332	0.0302	0.0291	0.0277	0.0258	0.0239	0.0263	0.0264	0.0254	0.0238	0.0234	0.0224	**−0.0126**
C28	0.0532	0.0566	0.0572	0.0514	0.0473	0.0449	0.0468	0.0424	0.0394	0.0441	0.0416	0.0361	0.0327	0.0323	0.0306	**−0.0225**
C29	0.0288	0.0294	0.0286	0.0243	0.0217	0.0206	0.0201	0.0171	0.0170	0.0186	0.0165	0.0150	0.0153	0.0154	0.0142	**−0.0146**
C30	0.0546	0.0514	0.0501	0.0449	0.0389	0.0344	0.0363	0.0335	0.0307	0.0307	0.0281	0.0262	0.0265	0.0260	0.0243	**−0.0303**
C31_C32	0.1921	0.2116	0.2222	0.2300	0.2093	0.2039	0.2070	0.1706	0.1846	0.1922	0.2097	0.2082	0.2250	0.2191	0.2258	**0.0337**
C33	0.0390	0.0414	0.0420	0.0380	0.0340	0.0302	0.0285	0.0255	0.0217	0.0221	0.0238	0.0215	0.0236	0.0240	0.0240	**−0.0151**
D35	4.2132	4.2808	4.5168	4.1947	3.7299	3.5017	3.2113	2.9186	2.9100	3.2698	3.1244	3.0671	3.1225	3.1627	3.1776	**−1.0356**
E36	0.2055	0.2066	0.1768	0.1641	0.1317	0.1232	0.1071	0.1083	0.1136	0.1152	0.1077	0.0941	0.0839	0.1007	0.1164	**−0.0891**
E37-E39	0.6725	0.7193	0.6107	0.5324	0.5272	0.5472	0.4986	0.3979	0.3971	0.4074	0.4386	0.4112	0.4683	0.4500	0.4463	**−0.2263**
F	0.0566	0.0580	0.0587	0.0533	0.0488	0.0448	0.0429	0.0386	0.0358	0.0364	0.0360	0.0332	0.0348	0.0357	0.0364	**−0.0202**
G45	0.0499	0.0566	0.0528	0.0499	0.0454	0.0421	0.0398	0.0370	0.0366	0.0404	0.0385	0.0353	0.0373	0.0385	0.0394	**−0.0105**
G46	0.0540	0.0583	0.0564	0.0526	0.0481	0.0431	0.0400	0.0359	0.0318	0.0341	0.0324	0.0299	0.0299	0.0306	0.0310	**−0.0229**
G47	0.0788	0.0854	0.0830	0.0772	0.0699	0.0631	0.0588	0.0544	0.0499	0.0520	0.0514	0.0469	0.0479	0.0480	0.0495	**−0.0293**
H49	0.3979	0.4082	0.4461	0.4128	0.3955	0.3551	0.3399	0.3291	0.3062	0.3388	0.3227	0.3119	0.3195	0.3253	0.3336	**−0.0643**
H50	1.5937	1.5550	1.5995	1.5040	1.4504	1.3368	1.3831	1.2927	1.1087	1.2723	1.2729	1.1984	1.1245	1.1163	1.1567	**−0.4369**
H51	1.7382	2.0385	2.0686	1.8462	1.5688	1.3398	1.2637	1.1825	1.0027	1.2177	1.1665	1.0448	1.0704	1.1088	1.1721	**−0.5661**
H52	0.1222	0.1340	0.1292	0.1162	0.1154	0.1038	0.1003	0.0974	0.0782	0.0828	0.0812	0.0776	0.0789	0.0852	0.0872	**−0.0350**
H53	0.0924	0.1043	0.0855	0.0769	0.0730	0.0690	0.0681	0.0600	0.0671	0.0659	0.0658	0.0654	0.0642	0.0660	0.0672	**−0.0252**
I	0.0819	0.0895	0.0884	0.0848	0.0786	0.0726	0.0666	0.0626	0.0625	0.0700	0.0656	0.0545	0.0585	0.0578	0.0597	**−0.0222**
J58	0.0055	0.0056	0.0049	0.0047	0.0044	0.0041	0.0040	0.0035	0.0043	0.0044	0.0044	0.0041	0.0043	0.0044	0.0041	**−0.0014**
J59_J60	0.0112	0.0116	0.0100	0.0098	0.0091	0.0097	0.0090	0.0085	0.0064	0.0065	0.0060	0.0057	0.0057	0.0057	0.0055	**−0.0057**
J61	0.0153	0.0166	0.0154	0.0149	0.0134	0.0122	0.0120	0.0109	0.0085	0.0092	0.0085	0.0085	0.0089	0.0088	0.0087	**−0.0066**
J62_J63	0.0340	0.0374	0.0373	0.0343	0.0309	0.0262	0.0241	0.0203	0.0178	0.0177	0.0175	0.0158	0.0163	0.0170	0.0178	**−0.0162**
K64	0.0179	0.0194	0.0193	0.0183	0.0169	0.0150	0.0137	0.0124	0.0117	0.0117	0.0118	0.0111	0.0116	0.0117	0.0115	**−0.0064**
K65	0.0228	0.0246	0.0230	0.0219	0.0187	0.0158	0.0145	0.0128	0.0131	0.0141	0.0142	0.0128	0.0132	0.0125	0.0117	**−0.0111**
K66	0.0178	0.0203	0.0200	0.0186	0.0161	0.0140	0.0123	0.0112	0.0115	0.0119	0.0118	0.0110	0.0116	0.0111	0.0114	**−0.0065**
L68	0.0142	0.0146	0.0144	0.0135	0.0126	0.0110	0.0102	0.0095	0.0084	0.0081	0.0080	0.0075	0.0076	0.0078	0.0080	**−0.0062**
M69_M70	0.0376	0.0383	0.0364	0.0354	0.0329	0.0294	0.0281	0.0262	0.0244	0.0260	0.0262	0.0244	0.0258	0.0247	0.0244	**−0.0131**
M71	0.0421	0.0448	0.0421	0.0401	0.0363	0.0325	0.0299	0.0279	0.0269	0.0320	0.0303	0.0265	0.0297	0.0290	0.0300	**−0.0121**
M72	0.0513	0.0558	0.0541	0.0532	0.0516	0.0491	0.0463	0.0438	0.0370	0.0380	0.0384	0.0361	0.0386	0.0396	0.0396	**−0.0117**
M73	0.0269	0.0291	0.0272	0.0255	0.0230	0.0215	0.0206	0.0192	0.0161	0.0179	0.0175	0.0164	0.0176	0.0183	0.0186	**−0.0083**
M74_M75	0.0410	0.0463	0.0451	0.0409	0.0376	0.0345	0.0316	0.0287	0.0270	0.0279	0.0296	0.0287	0.0299	0.0325	0.0328	**−0.0081**
N	0.0645	0.0683	0.0667	0.0606	0.0546	0.0476	0.0445	0.0403	0.0377	0.0399	0.0398	0.0363	0.0396	0.0393	0.0402	**−0.0244**
O84	0.0987	0.1008	0.1037	0.1007	0.0932	0.0813	0.0754	0.0718	0.0674	0.0687	0.0668	0.0622	0.0627	0.0650	0.0677	**−0.0310**
P85	0.0767	0.0792	0.0755	0.0692	0.0646	0.0574	0.0544	0.0505	0.0494	0.0517	0.0529	0.0504	0.0553	0.0562	0.0554	**−0.0213**
Q	0.0651	0.0672	0.0635	0.0599	0.0556	0.0529	0.0507	0.0484	0.0450	0.0453	0.0458	0.0424	0.0449	0.0461	0.0467	**−0.0185**
R_S	0.0874	0.0917	0.0892	0.0850	0.0811	0.0753	0.0709	0.0673	0.0658	0.0678	0.0682	0.0643	0.0669	0.0693	0.0697	**−0.0177**
T	0.0011	0.0012	0.0011	0.0010	0.0009	0.0009	0.0008	0.0007	0.0011	0.0011	0.0011	0.0010	0.0011	0.0010	0.0010	**−0.0001**

Appendix B

Table B1

Table B1
Decomposition results of global carbon intensity.

Year	Single-period decomposition results energy mix	energy intensity	economic structure	total	Multi-period-decomposition results energy mix	energy intensity	economic structure	total
2000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2001	0.9968	1.0599	1.0074	1.0644	0.9968	1.0599	1.0074	1.0644
2002	1.0046	1.0308	0.9739	1.0085	1.0014	1.0925	0.9812	1.0734
2003	1.0117	0.9196	1.0250	0.9536	1.0130	1.0046	10,057	1.0236
2004	1.0016	0.9057	1.0373	0.9411	1.0147	0.9099	1.0433	0.9632
2005	0.9707	0.9436	1.0606	0.9715	0.9850	0.8586	1.1064	0.9358
2006	1.0040	0.9304	1.0381	0.9698	0.9890	0.7989	1.1486	0.9075
2007	1.0018	0.9145	1.0279	0.9418	0.9908	0.7306	1.1807	0.8546
2008	0.9983	0.9521	0.9900	0.9410	0.9891	0.6956	1.1689	0.8042
2009	0.9955	1.1421	0.9545	1.0853	0.9847	0.7944	1.1157	0.8728
2010	0.9974	0.9628	10,252	0.9846	0.9822	0.7649	1.1439	0.8593
2011	1.0039	0.9386	1.0013	0.9529	0.9860	0.7179	1.1568	0.8189
2012	1.0004	1.0153	1.0022	1.0180	0.9864	0.7289	1.1594	0.8337
2013	0.9980	1.0133	0.9978	1.0090	0.9844	0.7386	1.1569	0.8412
2014	1.0031	1.0133	0.9949	1.0112	0.9874	0.7484	1.1510	0.8506

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Appendix C

Fig. C1, Fig. C2.

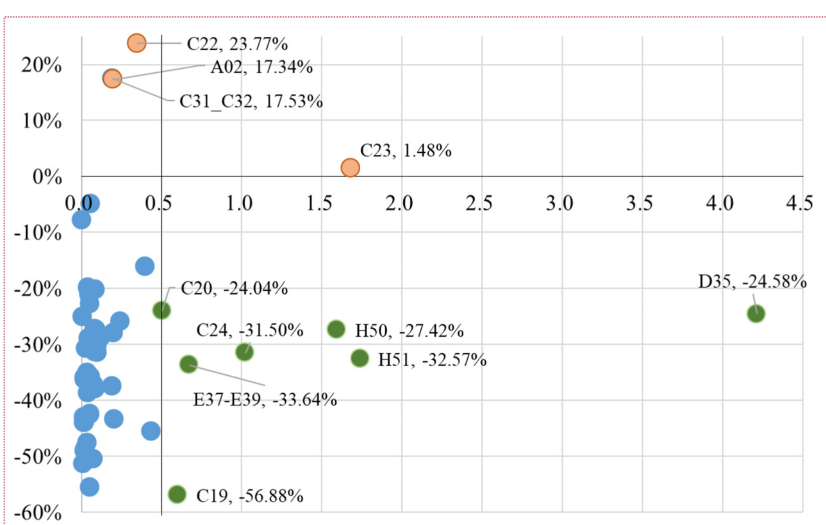

Fig. C1. Initial industrial classification.

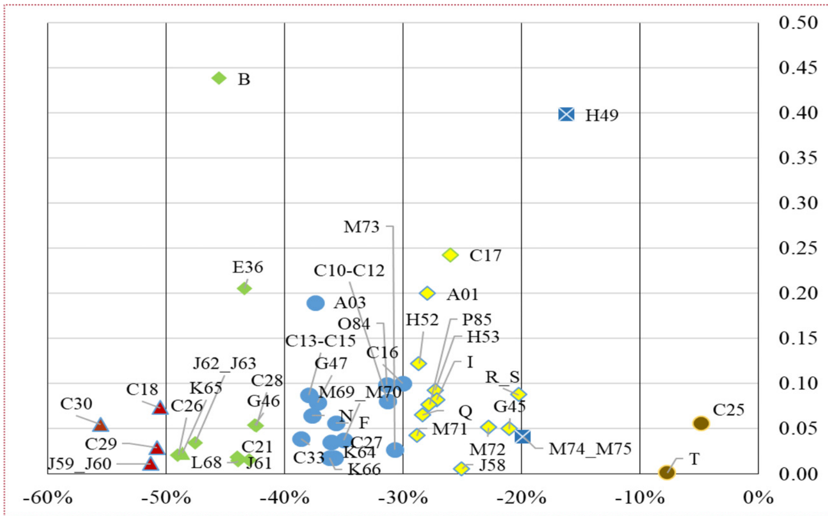

Fig. C2. Refined industrial classification.

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