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Structural decomposition analysis of energy-related CO_2 emissions in China from 1997 to 2010

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Abstract The energy-related CO_2 emissions in China have increased dramatically from 3384 to 8333×10^6 t during the last decade. To interpret these drastic changes, we undertake a structural decomposition analysis to decompose the changes in CO_2 emissions from 1997 to 2010 into the following six driving forces: emission coefficient, energy intensity, Leontief, sectoral structure, demand allocation (the shares of consumption, investments, and exports in final demand), and final demand effects. The results show that declines in energy intensity had a decrease impact on CO_2 emissions during the studied period. Changes in the relative importance of intermediate production in total output (the Leontief effect) contributed to decrease CO_2 emissions in the 2000–2002 period and to increase emissions in the other periods. The most important driver behind the steady increase in CO_2 emissions is the large increase in final demand. A further analysis at the sectoral level revealed differences and fluctuations between sectors. Energy intensity fell most strongly in the electric power sector and the coking, gas, and petroleum production sector (two energy-intensive sectors). The shift toward exports and investment increased CO_2 emissions (demand allocation effect). Part of the increases in CO_2 emissions thus stem from production activities for consumption activities elsewhere.

Keywords Input–output analysis · Structural decomposition analysis · Energy-related CO_2 emissions · China

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Introduction

The constant economic development of China since the beginning of the economic reform and openness processes initiated in 1978 have caused China's CO_2 emissions to exceed the European Union's and US total emissions in 2003 and 2007, respectively, making China the largest CO_2 emitting country in the world.

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In Fig. 1, the total CO_2 emissions from 1997 to 2010 in China, USA, and the EU are given. CO_2 emissions in the European Union declined from 4298.9 to 4142.6×10^6 t between 1997 and 2010, whereas in USA, the emissions increased slightly, from 6081.2 to 6144.9×10^6 t. Compared with the negligible changes of CO_2 emissions that took place in the European Union and USA, CO_2 emission in China increased drastically from 3384 to 8333×10^6 t (Rühl 2011).

This dramatic change in CO_2 emissions has attracted the attention of Chinese policy makers and researchers. In order to understand the driving forces behind the changes in CO_2 emissions and energy consumption, researchers have applied various decomposition methods, of which the most popular have been the index decomposition analysis (IDA) and the structural decomposition analysis (SDA).

The IDA has been applied by most of the researchers studying the changes in energy intensity and CO_2 emissions in China. The main reason why they chose this decomposition method is the availability of the data and the ease of use. For instance, Zhang (2003) and Fisher-Vanden et al. (2004) analyzed the driving forces of the decline in energy intensity in the 1990s. On the other hand, Liao et al. (2007), Ma and Stem (2008), Zha et al. (2009), Zhao et al. (2010), and Nie and Kemp (2013) discussed the fluctuation of energy intensity. Zhang et al. (2011) and Zhao et al. (2012) decomposed energy consumption in specific sector of China. Zhang et al. (2009), Lin and Moubarak (2013), Kang et al. (2014), and Xu et al. (2014) decomposed the changes of energy-related CO_2 emissions using IDA methods in China. However, there are some limitations to this IDA method that have to be kept in mind. First, IDA is based on final demand rather than total output, thus giving an incomplete description of energy intensity, which is generally calculated by the ratio between energy consumption and gross domestic product (GDP). Second, IDA works with indices rather than matrices; therefore, it is difficult to account for structural effects. Third, the intensity effect (also known as the efficiency effect) in IDA is normally treated as the residual of the decomposition, so the share that cannot be explained by structure effect. In summary, due to the above limitations, IDA is more suitable for analysis at the sector level rather than at the economy level.

The SDA permits the analyst to study structural changes in the economy by means of input–output data (Hoekstra and Van Den Bergh 2003; Cellura et al. 2012). SDA has been seldom applied in the past to analyze changes in energy consumption and CO_2 emissions in China, because of the availability of input–output tables and the relative higher complexity of performing input–output analysis.

However, several researchers have recently applied SDA to analyze issues related to energy consumption and CO_2 emissions in China, such as Zhang (2009, 2010), Peng and Shi (2011), Lan et al. (2012), and Zhang (2012). Nevertheless, there are still some problems to be addressed in previous studies. First, the effect of energy intensity to CO_2 emissions has not been interpreted adequately; and second, there exist different points of views on the contribution to CO_2 emissions from exports in previous studies (Du et al. 2011; Xu et al. 2011; Weber et al. 2008).

In this study, we will analyze the dramatic increase in CO_2 emissions in China over the past years. We will use the SDA method as we will study at the level of the whole economy rather than at sectoral level. In this sense, it is important to note that the contribution of economic growth to CO_2 emissions is much more important than the effect of increasing population, because CO_2 emissions per capita increased from 2.74 t in 1997 to 6.21 t in 2010, whereas CO_2 emissions intensity

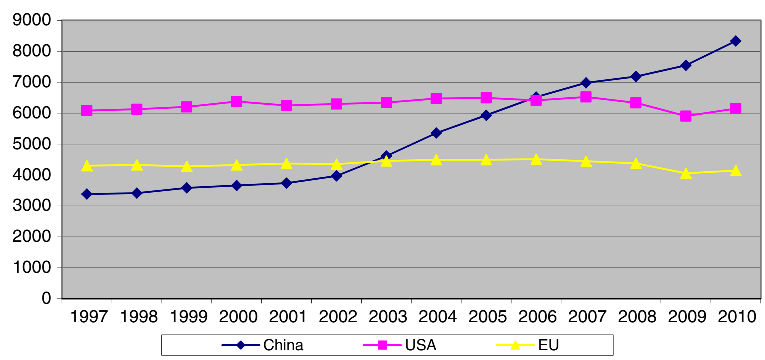

Fig. 1 Total CO_2 emissions (in million tons) from 1997 to 2010 in China, USA, and the EU. Data source: BP statistical review of world energy June 2011

decreased from 4.28 to 2.08 t per 10,000 Yuan GDP (National Bureau of Statistics (NBS) 2013; Rühl 2011). Our SDA will cover energy-related CO_2 emissions in China over the period of 1997–2010. Most of the previous studies are based on data previous to the year 2005 which shows the novelty of this paper.

In order to analyze the latest changes in energy consumption and CO_2 emissions, we decompose CO_2 emissions into the following six driving forces: the carbon content of energy, energy intensity, Leontief (inputs to produce intermediate output), sector structure, demand allocation (the shares of consumption, investments, and export in final demand), and final demand effects. The demand allocation effect is a new driving force which has not been analyzed in other studies before. This driving force is analyzed in depth together with the energy intensity and Leontief effect. Thus, in this study, we will contribute to the literature on a topic that has been inadequately addressed so far. An overview of the literature of relevant SDA studies is given in "Literature review" section. "Methodology" section provides insights in the methodology used in order to analyze the latest changes in energy consumption and CO_2 emissions. In "Sources of data and system definition" section, the sources of data and system definition will be elaborated in more detail. The results from the SDA are presented and discussed in "Results and discussion" section. "Conclusion" section will conclude this paper and offer details about policy goals.

Literature review

With the introduction of the input–output analysis (IOA) framework (Leontief 1967) and the development of structural economics, it has become possible to decompose energy consumption and CO_2 emissions by means of IOA. Several researchers have applied IOA to study changes in energy consumption in the 1980s. Gould and Kulshreshtha (1986) established an input–output model to analyze the changes in energy use between 1974 and 1979 in the Canadian province of Saskatchewan from the perspective of structural change and demand, concluding that final demand had been the main driver behind the increase in energy use. Likewise, Gowdy and Miller (1987) developed a method to examine the driving forces behind changes in energy use in the USA between 1963 and 1977 using IOA. These studies are considered pioneering attempts at structural decomposition.

The SDA method was formally established and further developed mainly in the 1990s. Among the first works, it is worth mentioning the study from Rose and Casler (1996), which analyzed five component categories comprising final demand, structure, trade, price, and other changes. Furthermore, they pointed out that the main shortcoming of previous studies was how they handled the interaction effect (the residual of the structural decomposition), which influenced the decomposing results to a different extent, and theorized a combination between SDA and the production function. In order to solve the issue of the interaction effect, Sun (1998) proposed a complete decomposition model. In this study, he put forward a methodology which permits to eliminate the residual of the decomposition by equally distributing it among the main effects. However, according also to this study, a problem still remains, which is that there is no rational explanation for an equal distribution of the residual. Dietzenbacher and Los (1998) further contributed to the solution of the issue of residuals in SDA. First, they showed that measures for various sources of change are not unique and then pointed out the issues posed by ad hoc methods. Second, they presented their own structural decomposition methodology, based on the use of an average value from the multiple decomposition results to express the final result. Third, the number of decomposition results depends on the number of determinants (n!) used. When the number of determinants is high, the number of decomposition results will be too large to be calculated. Therefore, they proposed two methods, two-polar decomposition and approximate decomposition with mid-point weights, which could be applied basically in every situation. Su and Ang (2012) made a distinction between the following four SDA methods: the ad hoc methods, the D&L methods (with D&L referring to Dietzenbacher and Los), the logarithmic mean Divisa index (LMDI), and the rest of methods. They also suggested some guidelines on the SDA method selection, concluding that LMDI is more adequate for one-stage decompositions, whereas the use of D&L is preferable when doing two-stage decompositions with more than five factors.

Recently, SDA has been widely applied in the field of energy consumption and CO_2 emissions. Wood (2009) decomposed greenhouse gas (GHG) in Australia over the period of 1976–2005 into ten effects, which consisted of the industrial efficiency, forward linkages, inter-industry structure, backward linkages, final demand mix, final demand destination, population affluence, population size, export mix, and export level effects. Using the LMDI approach, he showed that the industrial efficiency, final demand mix, destination, and export mix effects decreased GHG emissions and the other effects played a converse role. A SDA for Brazil was conducted by Wachsmann et al. (2009), which decomposed the energy use in Brazil over the 1970–1996 period into eight factors, including energy intensity, input mix, product mix, final demand destination, affluence, population in industrial energy use, residential energy use per capita, and population in residential energy use. According to the results, of the eight contributing factors, the input mix, product mix, affluence, population in industrial energy use, and population in residential energy use effects increased energy use in Brazil and converse effects were played by the others. They established that affluence and population accounted for 85.1 % of the increase in energy use. Lim et al. (2009) undertook a SDA on CO_2 emissions in Korea over the period of 1990–2003 and decomposed the change of emissions into eight factors, comprising carbon intensity, energy intensity, economic growth, final demand, exports, final demand imports, intermediate goods imports, and production technology. Out of these, energy intensity, economic growth, and exports played a positive role on the increase of CO_2 emissions, and opposite roles were played by the other factors. Among these factors, economic growth was the largest contributor to the increase in emissions. Cellura et al. (2012) conducted a SDA on air emission changes in the household sector in Italy for the period of 1999–2006. Combining two methodologies, the complete decomposition model proposed by Sun (1998) and the two-polar decompositions method proposed by Dietzenbacher and Los (1998), they decomposed the changes in air emissions into three factors consisting of the emission intensity, Leontief, and final demand effects. According to the results, the final demand and Leontief effects drove emissions up, whereas the emission intensity effect contributed negatively over the whole period. In addition, the final demand effect was found to be the most significant.

In the case of China, various studies detected reasons for increases of CO_2 emissions in China using SDA. Follow-up studies attempted to analyze the changes of CO_2 emissions in China from various aspects. Peters et al. (2007) pointed out that economic growth contributed most to CO_2 emissions with energy efficiency improvement offsetting part of the total increase. Guan et al. (2008) analyzed the driving forces behind CO_2 emissions in China and forecasted the changing trend of CO_2 emissions in China until 2030. The results of this study showed that efficiency improvement is the only effect offsetting the increase of CO_2 emissions and that it would be not enough to hold back the future increase of CO_2 emissions in China. Zhang (2009) studied the changes of energy-related carbon emission intensity over the period of 1992–2006, decomposing the changes into six driving forces, including the carbon, fuel mix, energy intensity, input mix,[1] product structure, and allocation structure factor. According to the results, the decline of carbon emission intensity is mainly due to the improvement of energy efficiency, whereas the effects of allocation structure contributed oppositely. It bears noting that the data used by the author before 2002 corresponds to official data from the China Statistical Yearbook (CSY), but the data from 2003 to 2006 was estimated by the author. Another study from Zhang (2010) is focused on the supply side. In this study, using the Ghosh input–output model and the SDA method proposed by Dietzenbacher and Los (1998), Zhang (2010) emphasized the effects of economic activity and economic structure on the increase of carbon emissions. Peng and Shi (2011) decomposed the changes in CO_2 emissions over the period of 1992–2005 into four factors comprising emission intensity, technology,[2] final demand, and trade. According to the results, the effects of final demand and technological change are two mainly reasons for the increase of CO_2 emissions, whereas the trade effect was not found to be significant in this study. Xia et al. (2012) analyzed the changes in energy intensity in China over the period of 1987–2005. According to the results, the decline of energy

[1] Input mix is the share of every kind of product or service in the total domestic intermediate input requirements of each sector.

[2] Technology refers to the Leontief inverse, which is confusing as changes in energy technology and fuel mix also involve technology changes.

intensity during the period of 1987–2002 is mainly due to the changes in the energy input coefficient factor (which represents the energy input mix for a certain product). Conversely, the increase of energy intensity during the period of 2002–2005 is mainly due to the changes in the Leontief inverse, having to do with inputs needed to produce intermediate output. Using the SDA method, Tian et al. (2013) analyzed the driving factors behind the increase of CO_2 emissions in Beijing and emphasized the effect of technological changes and structural shifts on the development of a decarbonized economy.

Focusing on the effect of technological changes, Lan et al. (2012) examined the increase of CO_2 emissions in China using marginal coefficients instead of average coefficients, finding that technological changes contributed more than structural shifts to emission abatement. With an emphasis on the regional differences in China, Feng et al. (2012) studied the driving forces behind CO_2 emission trends in China at the regional level, and the results showed that, relative to the eastern coastal zone, the CO_2 emissions in central and western zones increased due to the transfer of energy-intensive sectors.

With a focus on the effect of exports on CO_2 emissions in China, various studies analyzed the reasons behind the increase of CO_2 emissions in China. Lin and Sun (2010) illustrated that China's emissions embodied in international trade balance were around 1024×10^6 t, accounting for 18.8 % of the total emissions, which implied that the increases of CO_2 emissions in China were partly due to the increase of exports. Xu et al. (2011) examined the changes of CO_2 emissions embodied in China's exports, and the results showed that 48 % of China's CO_2 emissions were caused by the manufacturing of export products. Among the driving factors, the export composition effect contributed most to CO_2 emissions in China, followed by the export volume effect. Zhang (2012) obtained differing results by analyzing the causes of changes of trade-related CO_2 emissions in China, indicating that the export volume effect is the most important effect behind the increase in CO_2 emissions embodied in the exports from China, even more important than the export composition effect. Dietzenbacher et al. (2012) argued that existing estimates of CO_2 emissions embodied in China's exports are significantly biased. By distinguishing between processing exports from normal exports, they concluded that China's embodied emissions in its exports would be overestimated by more than 60 % if the distinction between processing exports and normal exports is not made.

In summary, from the presented literature review, it can be argued that economic growth is the most important factor behind the increase in CO_2 emissions in China, whereas the export effect is becoming increasingly important. Conversely, the improvement of energy efficiency is generally the most important effect in offsetting the increase of CO_2 emissions. However, there are still other effects to be interpreted further, such as intermediate output and sectoral structural effects.

Methodology

In the literature on SDA, we have seen that it is common to decompose CO_2 emissions into several effects including carbon intensity, energy intensity, inputs to produce intermediate output–Leontief effect, and demand side effects (demand structures and final demand in some studies). In this study, we go one step further and decompose demand side effect further into three effects, namely, (1) sector structure, (2) demand allocation, and (3) final demand effect. The second, demand allocation effect, is analyzed in depth together with the energy intensity and Leontief effect. Subsequently, we are able to interpret the reasons for the fluctuation of energy intensity and the energy-intensive sectoral

Table 1 List of driving forces

Driving force	Explanation
Emission coefficient	CO_2 emission coefficient of energy
Energy intensity	The quantity of energy required per unit output or activity
Leontief effect	The inputs needed to produce intermediate outputs
Sector structure	The share of final demand for each sector
Demand allocation	The shares of consumption, investments, and exports in final demand
Final demand	Changes of GDP per capita and population

structures, and we also point out the problems of excessive investment and exports and insufficient consumption.

In our analysis, six driving forces (see Table 1) are used to decompose CO_2 emissions in China from 1997 to 2010. The reason for using 1997 as a start date is that that year marked a steeper growth path for GHG emissions. Given our interest in understanding the rapid increase in GHG emissions, 1997 is a sensible start year. The most recent year for which input–output tables are available is the year 2010, which clarifies the end date of this research (NBS 2010, 2013). The analysis of the six driving forces is sub-divided into five different periods based on the availability of input–output tables (which meant that not all periods are equal in length).

Because of perfect solution for residual of decomposition and preferable ability of dealing with more than five factors structural decomposition, we choose for the method proposed by D&L as the method for our study (Dietzenbacher and Los 1998). In addition, because the number of determinants is high and the two-polar decomposition method is valid, we conduct our calculation by two-polar decomposition.

Input–output analysis

Input–output analysis is based on input–output tables, which can show the transformation relationship between different sectors. The basic input–output relationship in IOA can be expressed as follows:

$$X_{n\times 1} = A_{n\times n}X_{n\times 1} + Y_{n\times 1} \tag{1}$$

where "n" is the number of economic sectors in our study, "X" is a $n\times 1$ vector which represents the total output in the form of goods of each sector in the whole economy, "A" is a $n\times n$ matrix which refers to the direct input coefficient matrix which can transfer the total output into direct input, and "Y" is a $n\times 1$ vector which represents the final demand (generally it is equal to GDP) of each sector; then, "AX" represents direct input which is also called intermediate output.

Equation (1) can be formulated as follows:

$$X_{n\times 1} = (I_{n\times n} - A_{n\times n})^{-1} \times Y_{n\times 1} \tag{2}$$

where "I" is a $n\times n$ unity matrix and $(\mathrm{I}-A)^{-1}$ is another coefficient matrix which is known as the Leontief inverse matrix (L). Hence, Eq. (2) can be also expressed as follows:

$$X_{n\times 1} = L_{n\times n} \times Y_{n\times 1} \tag{3}$$

Due to the relationship between the Leontief inverse matrix (L) and the total input coefficient matrix (T), and the existence of the T matrix in CSY, we derive the L matrix from the T matrix, which is described as $L=T+I$. The Leontief inverse reflects the relationship between the final demand and the total output, which consists of direct output (final demand) and intermediate output.

Furthermore, Y can be expressed as

$$Y_{n\times 1} = S_{n\times d} \times D_{d\times 1} \times F \tag{4}$$

where S is a $n\times d$ matrix (d corresponds to the categories of allocation of final demand) which represents the sectorial structure; D is a $d\times 1$ vector which represents the demand allocation, that is, the shares of consumption, investment, and export in final demand; and F represents the final demand of the whole economy. X can be thus expressed as

$$X_{n\times 1} = L_{n\times n} \times S_{n\times d} \times D_{d\times 1} \times F \tag{5}$$

On the other hand, CO_2 emissions can be expressed as follows:

$$C = P \times E_{1\times n} \times X_{n\times 1} \tag{6}$$

where C is the total CO_2 emissions (in physical units), P is the CO_2 emission coefficient, and E is a $1\times n$ matrix which represents energy intensity of each sector. Instead of the final demand (Y), we use the total output (X) to interpret the relationship between CO_2 emissions and the output, because total output consists of intermediate output and final demand, each of which generates CO_2 emissions.

The units of CO_2 emissions (C), CO_2 emissions coefficient (P), energy intensity (E), and final demand (F) are, respectively, ton, tons per ton coal equivalent (tce), tce per 10,000 Yuan, and 10,000 Yuan. The units of Leontief inverse matrix (L), sector structural matrix (S), and demand allocation vector (D) are all percentages.

Finally, we derive the final expression for CO_2 emissions by combining Eqs. (5) and (6) as follows:

$$C = P \times E_{1\times n} \times L_{n\times n} \times S_{n\times d} \times D_{d\times 1} \times F \tag{7}$$

Structural decomposition analysis

Following the decomposition method proposed by Dietzenbacher and Los (1998), the changes in CO_2 emissions between a target year (t) and a reference year (0) can be decomposed in additive form as follows:

$$\begin{aligned}\Delta C &= C^t - C^0 = P^tE^tL^tS^tD^tF^t - P^0E^0L^0S^0D^0F^0\\ &= \Delta PE^tL^tS^tD^tF^t + P^0E^tL^tS^tD^tF^t - P^0E^0L^0S^0D^0F^0\\ &= \Delta PE^tL^tS^tD^tF^t + P^0\Delta EL^tS^tD^tF^t + P^0E^0L^tS^tD^tF^t - P^0E^0L^0S^0D^0F^0\\ &= \Delta PE^tL^tS^tD^tF^t + P^0\Delta EL^tS^tD^tF^t + P^0E^0\Delta LS^tD^tF^t + P^0E^0L^0S^tD^tF^t - P^0E^0L^0S^0D^0F^0\\ &= \Delta PE^tL^tS^tD^tF^t + P^0\Delta EL^tS^tD^tF^t + P^0E^0\Delta LS^tD^tF^t + P^0E^0L^0\Delta SD^tF^t + P^0E^0L^0S^0D^tF^t\\ &\quad - P^0E^0L^0S^0D^0F^0\\ &= \Delta PE^tL^tS^tD^tF^t + P^0\Delta EL^tS^tD^tF^t + P^0E^0\Delta LS^tD^tF^t + P^0E^0L^0\Delta SD^tF^t + P^0E^0L^0S^0\Delta DF^t\\ &\quad + P^0E^0L^0S^0D^0F^t - P^0E^0L^0S^0D^0F^0\\ &= \Delta PE^tL^tS^tD^tF^t + P^0\Delta EL^tS^tD^tF^t + P^0E^0\Delta LS^tD^tF^t + P^0E^0L^0\Delta SD^tF^t + P^0E^0L^0S^0\Delta DF^t\\ &\quad + P^0E^0L^0S^0D^0\Delta F\end{aligned} \tag{8}$$

However, according to Dietzenbacher and Los (1998), Eq. (8) is only one of the many forms of possible decomposition, and the number of different decomposition forms equals to the number of permutations of the set of determinants (n!). In this case, there are 720 (6!) forms of decomposition. We simply use the two-polar decomposition method which has been found to involve few calculations and yield estimates close to the average value of the full set of decompositions (Dietzenbacher and Los 1998). In this case, the first polar decomposition corresponds to Eq. (8), and the other can be expressed as

$$\begin{aligned}\Delta C &= C^t - C^0 = P^tE^tL^tS^tD^tF^t - P^0E^0L^0S^0D^0F^0\\ &= \Delta PE^0L^0S^0D^0F^0 + P^t\Delta EL^0S^0D^0F^0 + P^tE^t\Delta LS^0D^0F^0\\ &\quad + P^tE^tL^t\Delta SD^0F^0 + P^tE^tL^tS^t\Delta DF^0\\ &\quad + P^tE^tL^tS^tD^t?F\end{aligned} \tag{9}$$

We finally obtain the final decomposition equation by calculating the average of the two-polar decompositions (Eqs. (8) and (9)).

$$\Delta C = C^t - C^0 = \Delta P + \Delta E + \Delta L + \Delta S + \Delta D + \Delta F \tag{10}$$

$$\Delta P = \frac{1}{2}\left(\Delta PE^tL^tS^tD^tF^t + \Delta PE^0L^0S^0D^0F^0\right) \tag{11}$$

$$\Delta E = \frac{1}{2}\left(P^0\Delta EL^tS^tD^tF^t + P^t\Delta EL^0S^0D^0F^0\right) \tag{12}$$

$$\Delta L = \frac{1}{2}\left(P^0E^0\Delta LS^tD^tF^t + P^tE^t\Delta LS^0D^0F^0\right) \tag{13}$$

$$\Delta S = \frac{1}{2}\left(P^0E^0L^0\Delta SD^tF^t + P^tE^tL^t\Delta SD^0F^0\right) \tag{14}$$

$$\Delta D = \frac{1}{2}\left(P^0E^0L^0S^0\Delta DF^t + P^tE^tL^tS^t\Delta DF^0\right) \tag{15}$$

$$\Delta F = \frac{1}{2}\left(P^0E^0L^0S^0D^0\Delta F + P^tE^tL^tS^tD^t\Delta F\right) \tag{16}$$

From Eq. (10), the different effects in which the change of CO_2 emissions from a reference year (0) to a target year (t) can be calculated, consisting of the emission (ΔP), energy intensity (ΔE), Leontief (ΔL), sector structural (ΔS), demand allocation (ΔD), and final demand (ΔF) effects.

Sources of data and system definition

For this study, the following three kinds of data have been gathered: input–output tables, energy consumption, and CO_2 emissions. Input–output tables correspond to the years 1997, 2000, 2002, 2005, 2007, and 2010 and are collected from the China Statistics Yearbook (NBS 2000, 2002, 2005, 2007, 2011, 2013). Because of this fact, apart from analyzing the change in emissions for the period of 1997–2010, it has also been possible to analyze the periods 1997–2000, 2000–2002, 2002–2005, 2005–2007, and 2007–2010. This higher resolution permits a more comprehensive study of the evolution of emissions and their sources of change. Moreover, the input–output data is at constant prices with 1997 as the base year. Energy consumption data of each economic sector is collected from China Energy Statistics Yearbook (DITSNBS 2001; DITSNBS and

EBNDRC 2004, 2008, 2013). Finally, the CO_2 emissions data is collected from the "BP statistical review of world" (Rühl 2011) and correspond only to energy-related emissions.

According to the input–output tables from CSY, the whole Chinese economy is divided in 17 sectors. For this reason, a 17-sector resolution has been chosen, and therefore, the number of sectors (i according to the methodology presented in "Input-output analysis" section) equals to 17. In addition, it is necessary to illustrate that final demand consists of consumption, investment, and export, which jointly make up final output of the domestic economy. Different with previous studies (Lim et al. 2009; Peng and Shi 2011), we use export instead of net export which is the difference of export and import. The underlying rationale is that, by deducting import from export, the final demand is underestimated because the whole export comes from final output.

Results and discussion

The results of the SDA are shown in Tables 2 and 3 and Fig. 2. During the period of 1997–2010, the increase of CO_2 emissions stems mainly from the increase of the final demand, which contributed 9.398×10^9 t of emissions, accounting for 189.91 % of the total. Apart from the final demand effect, the Leontief effect had also a significant contribution, with 2.647×10^9 t (53.5 % from the total); the sector structural and demand allocation effects increased emissions by 8.10 and 6.99 %, respectively; and the emission coefficient effect has a marginal contribution (3.26 % from the total). Of all six effects, the energy intensity effect is the only one which decreases CO_2 emissions, concretely accounting for −161.76 % from the total. To simplify our analysis, we put the last three factors together which are all from demand side and call it demand side effect. So, we undertake our analysis from four aspects comprising emission coefficient, energy intensity, Leontief, and demand side effects.

Emission coefficient effect

The emission coefficient effect corresponds to the CO_2 emissions coefficient of energy. According to Fig. 2, the emission coefficient hardly changed and had a negligible influence over the studied period, since it only contributed to 3.26 % of the total change in emissions. However, there can be observed a certain asymmetry regarding the contribution of the effect in the different sub-periods. The possible explanation of these differences could be the changes of energy mix in China. According to Table 4, the percentage of coal in the total energy consumption declined from 1997 to 2002 and then increased after 2002.

In general, the slight increase of the emission coefficient in the period of 1997–2010 shows that the carbon content of the energy mix has not improved and even became slightly worse in later years. The economical development of China still mainly relied on fossil fuels, with coal being responsible for three quarters of energy use. The percentage of "hydropower, nuclear power, and other power" increased slightly by 1.5 % in the past decade; it went up from 2.0 to 2.6 % between 1997 and 2002 and stayed at the level in the period of 2002–2007, then continued to go up to 3.5 % in 2010. The share of natural gas doubled but is still low compared to the share of coal and petroleum.

Energy intensity effect

The energy intensity effect is the only driving force which consistently helped to reduce emissions during the period of 1997–2010, contributing to decrease CO_2 emissions by 8.005×10^9 t, which accounted for −161.76 % from the total.

As shown in Table 5, from 1997 to 2010, the energy intensity decreased in all sectors of the Chinese economy. Of the different sectors, the "production and supply of electric power, heat power, and water" (EHW) sector experienced the biggest decrease in energy intensity, from 2.19 to 0.44 tce/10,000 Yuan, followed by the "coking, gas, and processing of petroleum" (CGP); "mining" (MIN); "transport, storage, post, information transmission, computer services, and software" (TSP); and "manufacture and processing of metals and metal products" (MPM) sectors. However, the energy intensity of these sectors is still relatively high compared to other economies such as Japan and Europe and has thus still potential for improvement. Energy intensity in the sectors "agriculture, forestry, animal husbandry, and fishery" (AFA); "manufacture of textile, wearing apparel, and leather products"

Table 2 Structural decomposition results for CO_2 emissions in China for the period of 1997–2010 (unit: million tons of CO_2)

Factors	1997–2000	2000–2002	2002–2005	2005–2007	2007–2010	1997–2010
Emission changes	275.6	310.5	1962.1	1047.5	1353.1	4948.8
Emission coefficient	32.1	−35.8	44.3	−46.7	200.6	161.3
Energy intensity	−958.7	−206.4	−1691.0	−1094.7	−1103.6	−8005.2
Leontief effect	276.2	−497.5	1191.1	439.7	−54.4	2647.2
Sector structure	89.8	−65.7	92.8	102.1	−104.0	400.9
Demand allocation	−13.9	27.3	158.7	15.9	14.0	346.1
Final demand	850.2	1088.6	2166.3	1631.1	2400.3	9398.5

Data sources: CSY (2000, 2002, 2004, 2007, 2010), CESY (1998, 2001, 2003, 2006, 2008), and BP (2011) and authors' calculation

(TWL); "construction" (CON); and "wholesale and retail trades, hotels, and catering services" (WHC) declined to a lesser extent. It can be thus concluded that, over the period of 1997–2010, the decline of energy intensity took place mainly in the most energy-intensive sectors.

Table 5 also shows that the changes in energy intensity varied significantly in some sectors during the four sub-periods. During the sub-period 1997–2000, a significant reduction in energy intensity took place in the EHW and CGP sectors, whereas the sector "manufacture of non-metallic mineral products" (MNM) increased its energy intensity by 40.83 %. During the sub-period 2000–2002, the total energy intensity declined slightly, but in some sectors, notably the CGP and EHW sectors, energy intensity increased. Lastly, it is worth noting that energy intensity declined sharply in the CGP and EHW sectors during the last sub-period, and energy intensity in the MNM sector declined instead of the significant increase in the sub-period 1997–2000.

The total energy intensity in the sub-period 2002–2005 declined dramatically, a finding which differs from the results obtained in previous studies, such as Liao et al. (2007) and Ma and Stem (2008). According to these studies, which utilized IDA, energy intensity increased in the period of 2002–2005, breaking the trend followed in the previous years. This fluctuation also drew the attention of other researchers. For instance, Liao et al. (2007) and Xia et al. (2012) tried to interpret it from the perspective of IDA and SDA, respectively. Ma (2010) argued that the increase in energy intensity from 2002 to 2005 was due to the misuse of the GDP deflator and used sector price indices instead. However, even by using sector price indices, energy intensity results did not vary significantly. It is worth investigating the reasons behind the differences in the results. In previous studies which applied IDA (Liao et al. 2007; Ma and Stem 2008), energy intensity has been defined as the energy consumption per 10,000 Yuan GDP, which thus corresponds to the final demand. However, energy is consumed by the total output rather than just by the final demand. In this study, we defined the energy intensity as the energy consumption per

Table 3 The relative results of structural decomposition (unit: percentage)

Factors	1997–2000	2000–2002	2002–2005	2005–2007	2007–2010	1997–2010
Emission changes	100	100	100	100	100	100
Emission coefficient	11.64	−11.53	2.26	−4.46	14.83	3.26
Energy intensity	−347.86	−66.48	−86.18	−104.50	−81.56	−161.76
Leontief effect	100.22	−160.24	60.70	41.98	−4.02	53.49
Sector structure	32.57	−21.17	4.73	9.75	−7.68	8.10
Demand allocation	−5.05	8.80	8.09	1.52	1.04	6.99
Final demand	308.48	350.63	110.40	155.71	177.40	189.91

Data sources: CSY (2000, 2002, 2004, 2007, 2010), CESY (1998, 2001, 2003, 2006, 2008), and BP (2011) and authors' calculation

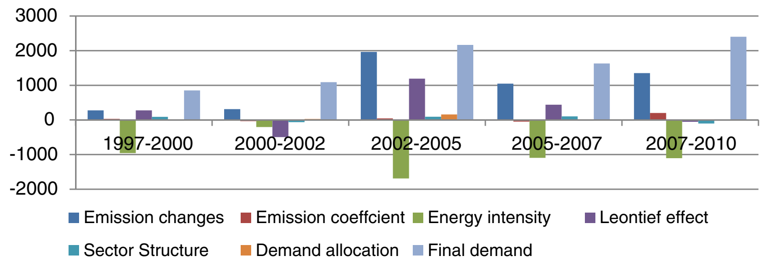

Fig. 2 The total emission changes and emission changes from the six effects in the period of 1997–2010 in the unit of million tons. Data sources: CSY (2000, 2002, 2004, 2007, 2010, 2013), CESY (1998, 2001, 2003, 2006, 2008, 2011), and BP (2011) and authors' calculation

10,000 Yuan from the total output, including thus the intermediate output and the final output, which is a more appropriate way of defining it. With regard to the changes in energy intensity in each sector, it is worth mentioning that in the CGP and EHW sectors, the energy intensity declined significantly in the sub-period 2002–2005 and increased in last sub-period.

The reductions in total energy intensity fluctuated; there was a big reduction in 1997–2000, followed by a small reduction in 2000–2002, a big reduction again in 2002–2005, and a moderate reduction in 2005–2007 and 2007–2010. It is unclear what caused the fluctuations. Energy prices are an obvious factor, and another possible factor is government policies. When the price of energy started to rise in 1990, the direction of technological change became more energy efficient (Ma and Stem 2008).

Leontief effect

As shown in Tables 2 and 3, over the period of 1997–2010, the Leontief effect, representing the inputs needed to produce intermediate outputs, contributed in 2.65×10^9 t to the increase of CO_2 emissions, which accounted for 53.49 % from the total. In detail, aside from the sub-periods 2000–2002 and 2007–2010, during which the Leontief effect contributed to reduce CO_2 emissions in 160.24 and 4.02 % from the total, in other sub-periods, the Leontief effect increased CO_2 emissions.

A number of studies have contributed to further understand the Leontief effect. For instance, Feldman et al. (1987), in a study into the sources of structural change in the USA, found that the increase of output was mainly due to the increase of final demand and the changes in the Leontief inverse was relevant only in some emerging and declining sectors. Moreover, according to the study by Afrasiabi and Casler (1991) for the USA, the changes in the Leontief inverse comprised both technological change and product mix change, with the former being overall more relevant. Furthermore, as a driving force behind the changes in the Leontief inverse, technological change can decrease the input for final demand; that is, it can cause a decrease in the intermediate output thereby decreasing the total output. With respect to product mix changes, due to the changes in the market and the incentive or restrictive policies, certain sectors would develop differently. Thus, if input-intensive sectors develop relatively fast, they would increase the production of intermediate outputs and therefore the total output as well. On the other hand, if less input-intensive sectors develop rapidly, the opposite is expected to happen. Hence, changes of product mix can either increase or decrease total output.

In the present study, the Leontief effect has contributed to the increase of CO_2 emissions in the sub-periods 1997–2000, 2002–2005, and 2005–2007, but an opposite effect in the sub-periods 2000–2002 and 2007–

Table 4 The shares of four energy forms in total energy consumption (percentages)

Year	Coal	Petroleum	Natural gas	Hydropower, nuclear power, and other power
1997	74.9	21.3	1.8	2.0
2000	72.4	23.1	2.3	2.1
2002	71.5	23.4	2.6	2.6
2005	74.1	20.7	2.8	2.5
2007	74.3	19.7	3.5	2.6
2010	71.9	20.0	4.6	3.5

Data source: CESY (2011)

Table 5 Changes of energy intensity in the unit of tce/10,000 Yuan by sector

Sectors	1997–2010	1997–2000	2000–2002	2002–2005	2005–2007	2007–2010
Agriculture, Forestry, Animal Husbandry, and Fishery (AFA)	−0.03846	−0.00122	0.00382	0.00183	−0.01135	−0.03155
Mining (MIN)	−0.82115	−0.19887	−0.08422	−0.39302	−0.07790	−0.06714
Manufacture of Foods, Beverage, and Tobacco (FBT)	−0.17336	−0.01798	0.02618	−0.09521	−0.04532	−0.04104
Manufacture of Textile, Wearing Apparel, and Leather Products (TWL)	−0.05018	−0.01297	0.04139	−0.01585	−0.02992	−0.03283
Other Manufacture (OTM)	−0.17434	0.06058	−0.08319	−0.06894	−0.06412	−0.01867
Production and Supply of Electric Power, Heat Power, and Water (EHW)	−1.74791	−1.15875	0.19491	−0.53687	−0.20417	−0.04304
Coking, Gas, and Processing of Petroleum (CGP)	−0.95954	−0.78477	0.30416	−0.34239	−0.12914	−0.00740
Chemical Industry (CHI)	−0.55435	−0.27928	0.05013	−0.17736	−0.05944	−0.08840
Manufacture of Non-Metallic Mineral Products (MNM)	−0.57644	0.52940	−0.00985	−0.55837	−0.28209	−0.25552
Manufacture and Processing of Metals and Metal Products (MPM)	−0.64262	−0.22763	−0.15952	−0.10070	−0.14116	−0.01360
Manufacture of Machinery and Equipment (MME)	−0.09323	−0.05732	−0.00219	−0.02584	−0.00624	−0.00163
Construction (CON)	−0.03959	−0.02153	−0.01172	−0.00194	−0.00435	−0.00004
Transport, Storage, Post, Information Transmission, Computer Services, and Software (TSP)	−0.82952	−0.35500	−0.16632	−0.28300	0.06364	−0.08884
Wholesale and Retail Trades, Hotels, and Catering Services (WHC)	−0.07020	−0.02253	−0.04176	−0.00385	0.01216	−0.01422
Real Estate, Leasing, and Business Services (RLB)	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Financial Intermediation (FII)	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Other Services (OTS)	−0.29757	−0.09706	−0.18627	0.00910	−0.00062	−0.02272
Total	−7.06848	−2.64494	−0.12446	−2.59241	−0.98003	−0.72664

Data sources: CSY (2000, 2002, 2004, 2007, 2010, 2013), CESY (1998, 2001, 2003, 2006, 2008, 2011), and authors' calculation

2010. According to the abovementioned, the Leontief effect reflects changes in intermediate output. To analyze this, we studied changes in the share of intermediate output to total output (see Table 6). In the sub-periods 1997–2000, 2002–2005, and 2005–2007, the share of intermediate output increased significantly, which means that changes in product mix played a much bigger role than technological change and that the direction of product mix change was toward input intensive sectors. In the sub-periods 2000–2002 and 2007–2010, the total share of intermediate output increased, but in several sectors, the share declined significantly, such as the "manufacture of machinery and equipment" (MME) or the production and supply of electric power, heat power, and water (EHW), among others, resulting in lower CO_2 emissions.

The conclusion from the above analysis is that in the period of 1997–2010, the economy of China became more input intensive and technological changes did not contribute enough to decrease the share of intermediate output in order to counterbalance that fact.

Demand side effect

Sector structure

As shown in Tables 2 and 3, over the period of 1997–2010, CO_2 emissions from the sector structure effect increased by 400.89×10^6 t, which accounted for 8.10 % from the total. In detail, the effect of the sector structure contributed to increase CO_2 emissions during the sub-periods 1997–2000, 2002–2005, and 2005–2007 and to reduce emissions during the sub-periods 2000–2002 and 2007–2010.

To further understand the effect of the sector structure, we have calculated the change in the share of final demand for each sector (see Table 7). During the sub-periods 1997–2000, 2002–2005, and 2005–2007, the shares of some energy intensive sectors increased, such as MPM, EHW, CGP, and TSP. However, in the sub-periods 2000–2002 and 2007–2010, the shares of some energy-intensive sectors declined, such as CGP, "chemical industry"

Table 6 Changes of ratio of indirect output in total output in the unit of percentage

Sectors	1997–2000	2000–2002	2002–2005	2005–2007	2007–2010	1997–2010
Agriculture, Forestry, Animal Husbandry, and Fishery (AFA)	−0.80	4.64	1.72	1.95	4.85	22.37
Mining (MIN)	−0.25	−0.87	4.55	−0.16	0.07	3.35
Manufacture of Foods, Beverage, and Tobacco (FBT)	−0.78	6.55	2.79	8.70	0.42	17.68
Manufacture of Textile, Wearing Apparel, and Leather Products (TWL)	3.36	−8.36	0.48	5.57	2.89	3.94
Other Manufacture (OTM)	0.51	1.93	1.78	−1.32	0.87	3.77
Production and Supply of Electric Power, Heat Power, and Water (EHW)	2.92	−5.90	5.03	1.19	−1.28	1.96
Coking, Gas, and Processing of Petroleum (CGP)	4.74	−2.54	0.13	0.55	0.62	3.50
Chemical Industry (CHI)	1.73	−0.08	2.61	−1.13	0.53	3.66
Manufacture of Non-Metallic Mineral Products (MNM)	−3.12	3.05	1.59	3.48	1.20	6.20
Manufacture and Processing of Metals and Metal Products (MPM)	0.40	0.67	−1.15	−0.96	3.14	2.10
Manufacture of Machinery and Equipment (MME)	1.62	−2.62	−3.36	3.81	−1.53	−2.08
Construction (CON)	0.33	0.39	2.12	−5.70	0.17	−2.68
Transport, Storage, Post, Information Transmission, Computer Services, and Software (TSP)	0.27	−2.28	0.46	−4.05	4.44	−1.16
Wholesale and Retail Trades, Hotels, and Catering Services (WHC)	3.58	−8.21	3.27	−6.93	3.90	−4.38
Real Estate, Leasing, and Business Services (RLB)	−0.18	5.97	−2.70	−8.85	−2.21	−7.97
Financial Intermediation (FII)	−1.13	7.12	−9.12	6.10	2.44	5.42
Other Services (OTS)	0.94	2.48	7.99	2.83	−1.30	12.94
Total	14.16	1.96	28.21	5.07	19.21	68.62

Data sources: CSY (2000, 2002, 2004, 2007, 2010, 2013), CESY (1998, 2001, 2003, 2006, 2008, 2011), and authors' calculation

(CHI), MNM, and MPM. It can be thus argued that over the studied period, the effect of sector structure changes increased CO_2 emissions mainly due to the increase in the share of final demand of energy-intensive sectors.

Demand allocation effect

Following, the effects of changes in the final demand categories consumption, investment, and export are explained. Over the period of 1997–2010, the demand allocation effect increased CO_2 emissions by 346.12×10^6 t, which accounted for 6.99 % from the total (see Tables 2 and 3). Apart from the sub-period 1997–2000, during which the demand allocation effect decreased CO_2 emissions by 13.92×10^6 t, in the other sub-periods, the demand allocation effect increased CO_2 emissions by 27.31×10^6 t (8.80 %), 153.74×10^6 t (8.09 %), 15.89×10^6 t (1.52 %), and 14.03×10^6 t (1.04 %), respectively.

To further explain the effect of demand allocation, we have disaggregated the changes in the shares of demand allocation into consumption, investment, and export. As shown in Table 8, in the sub-period 1997–2000, the share of consumption from the final demand increased and the share of investment declined, and because of this, the demand allocation effect decreased CO_2 emissions by 13.92×10^6 t, accounting for 5.05 % from the total. In contrast, in the sub-periods 2000–2002, 2002–2005, and 2005–2007, the shares of consumption in the final demand declined and the shares of investment increased, and therefore, CO_2 emissions from demand allocation effect increased. Whereas in the sub-period 2007–2010, although the share of consumption increased, but relative to the sharp increase of share of investment, the small increase of share of consumption cannot offset the increase of CO_2 emissions. It can be thus argued that the increase in the share of consumption contributed to decrease CO_2 emissions, whereas the increase in the

Table 7 Changes of the shares of each sector in final demand in the unit of percent

Sectors	1997–2000	2000–2002	2002–2005	2005–2007	2007–2010
Agriculture, Forestry, Animal Husbandry, and Fishery (AFA)	−0.0190	−0.0308	−0.0303	−0.0100	−0.0076
Mining (MIN)	0.0004	0.0002	−0.0037	0.0005	0.0003
Manufacture of Foods, Beverage, and Tobacco (FBT)	−0.0141	−0.0288	0.0029	−0.0014	0.0046
Manufacture of Textile, Wearing Apparel, and Leather Products (TWL)	−0.0179	−0.0097	0.0015	−0.0006	−0.0115
Other Manufacture (OTM)	−0.0076	0.0000	−0.0002	0.0057	−0.0033
Production and Supply of Electric Power, Heat Power, and Water (EHW)	0.0012	0.0026	−0.0013	0.0004	0.0014
Coking, Gas, and Processing of Petroleum (CGP)	−0.0006	−0.0001	0.0017	0.0001	−0.0010
Chemical Industry (CHI)	−0.0001	−0.0070	−0.0008	0.0045	−0.0020
Manufacture of Non-Metallic Mineral Products (MNM)	−0.0029	−0.0043	0.0018	−0.0021	−0.0001
Manufacture and Processing of Metals and Metal Products (MPM)	0.0001	−0.0014	0.0081	0.0089	−0.0137
Manufacture of Machinery and Equipment (MME)	0.0361	−0.0048	0.0712	−0.0033	0.0086
Construction (CON)	0.0069	−0.0095	−0.0169	0.0101	0.0182
Transport, Storage, Post, Information Transmission, Computer Services, and Software (TSP)	0.0040	0.0032	0.0148	−0.0017	−0.0046
Wholesale and Retail Trades, Hotels, and Catering Services (WHC)	−0.0062	0.0214	−0.0090	−0.0003	−0.0064
Real Estate, Leasing, and Business Services (RLB)	0.0089	0.0012	−0.0099	0.0049	0.0126
Financial Intermediation (FII)	0.0028	−0.0032	0.0041	−0.0009	−0.0006
Other Services (OTS)	0.0079	0.0710	−0.0339	−0.0148	0.0051
Total	0.0000	0.0000	0.0000	0.0000	0.0000

Data sources: CSY (2000, 2002, 2004, 2007, 2010, 2013) and authors' calculation

share of investment played a decreasing role. Moreover, from 2000 to 2010, the increase in the share of investment and the decrease in the share of consumption was the main reason for the increase of CO_2 emissions from the demand allocation effect.

The demand allocation effect for China is different than those for some other countries. Wood (2009) decomposed Australia's greenhouse gas emissions into 11 effects using SDA and concluded that demand destination effect (the shares of consumption and investment in total; export was discussed in another effect) decreased greenhouse gas emissions during the studied period. Wachsmann et al. (2009) likewise applied SDA on the energy use in Brazil and found that the demand destination effect (the shares of consumption, investment, and export in total) led to a reduction of energy use. In China, however, we observe an increase in CO_2 emissions due to the effect of demand allocation. The reason for this is that the shares of investment and export increased, two demand categories which are relatively energy- and carbon-intensive compared to consumption. The export-related CO_2 emissions are for products consumed elsewhere. If the products were produced in countries with more energy-efficient processes and less carbon-intensive fuels, total CO_2 emissions would be lower.

Several researchers have included the role of exports in their study; however, only a few studies have focused on this as the primary issue. Their method differs slightly from what is used in this paper; we use export instead of net export which is the difference of export and import (by deducting import from export the final demand is underestimated because the whole export comes from final output), which is used in the work from, among others, Lim et al. (2009) and Peng and Shi (2011). Xu et al. (2011) examined the export composition and total export volume which is methodologically also different to the analysis presented here. The study of Weber et al. (2008), using a related method to ours, found that in 2005, around one third of Chinese emissions (1700 mt CO^2) were due to production of exports, and this proportion has risen over the last decades. This result is in line with ours as we discovered a positive correlation between high exports and CO_2 emissions.

Table 8 Changes of demand allocation from 1997–2010 in the unit of percent

Demand allocation	1997–2000	2000–2002	2002–2005	2005–2007	2007–2010
Consumption	0.45	−1.79	−8.76	−0.66	0.21
Investment	−2.72	1.67	1.91	0.15	5.76
Export	2.27	0.12	6.85	0.51	−5.97
Total	0.00	0.00	0.00	0.00	0.00

Data sources: CSY (2000, 2002, 2004, 2007, 2010, 2013) and authors' calculation

Final demand

The final demand effect is the biggest contributor to the increase of CO_2 emissions over the period of 1997–2010, which increased drastically by 9.40×10^9 t, accounting for 189.91 % of the total. This trend has been uniform during the different sub-periods. In this period, final demand increased from 8950 to 41396 billion Yuan, which accounts for 362.53 % of the total, with an annual average increase of 14 %. Therefore, the rapid economic development of China can be regarded as the main driving factor behind the increase of CO_2 emissions over the period of 1997–2010.

The changes of final demand could be further disaggregated into changes of GDP per capita and population, and these are shown in Table 9 for each sub-period. As it can be observed, the growth rate of GDP per capita is far larger than that of population. It can be thus concluded that the growth of GDP per capita is the main reason behind the increase of final demand. Therefore, from the perspective of final demand, the increase of CO_2 emissions is mainly due to economic growth rather than population growth.

A similar phenomenon took place in other countries as well. For instance, during the period of 1972–1982, CO_2 emissions is USA decreased from 4790.1 to 4676.0×10^6 t, a reduction of 114.1×10^6 t. However, the effect of final demand increased CO_2 emissions by 528.8×10^6 t, mainly due to the growth of USA's economy (Casler and Rose 1998). Also, in Australia, during the period of 1990–2005, final demand contributed to increase CO_2 emissions, mainly due to the effect of economic growth (Wood 2009). Moreover, CO_2 emissions increased by 50.7×10^6 t in Korea during the period of 1990–2003, with the effect of economic growth accounting for 90.24 % of the total increase in CO_2 emissions (Lim et al. 2009). Lastly, Norway is yet another example in which the effect of economic growth had a central role in the increase of CO_2 emissions during the period of 1990–2002 (Yamakawa and Peters 2011).

Conclusions

In this study, we have analyzed the dramatic increase of CO_2 emissions in China in the last years by means of a SDA based on the two-polar decomposition method (Dietzenbacher and Los 1998), decomposing the changes of emissions in China from 1997 to 2010. Changes of CO_2 emissions were decomposed into the following six effects: changes in emission coefficient (of energy), energy intensity, inputs per unit of intermediate output (Leontief effect), sectoral structure, demand allocation, and final demand effect. According to the results, energy intensity contributed to significantly decrease CO_2 emissions. Larger decreases in energy intensity took place in the electric power sector and the coking, gas, and petroleum production sector, two relatively energy-intensive sectors. With regard to the other factors, we found that changes in the relative importance of intermediate production in total output (the Leontief effect) entailed a decrease in CO_2 emissions in the 2000–2002 and 2007–2010 periods and an increase in the other periods. Moreover, the shift toward exports and investment increased CO_2 emissions by means of the demand allocation effect. The most important driver behind the steady increase in CO_2 emissions is the large increase in final demand.

The influence of technological change was mostly observed through the energy intensity effect. Our analysis of the Leontief effect revealed that technological changes did not have a noticeable effect on the decrease of input from the final demand. Our explanation for this is the following: as a result of the decline of energy intensity, the input of energy to final demand decreased. But due to the changes of Leontief inverse, total input

Table 9 Changes of influence factors of final demand during 1997–2010 in the unit of percent

Influence factors	1997–2000	2000–2002	2002–2005	2005–2007	2007–2010	1997–2010
Population	2.52	1.35	1.79	1.05	1.48	8.47
GDP per capita	22.54	19.67	50.98	42.24	48.73	368.38

Data sources: CSY (2000, 2002, 2004, 2007, 2010, 2012) and authors' calculation

from all kinds of intermediate products to produce final output increased. The product mix thus became more input-intensive, both in terms of material inputs and energy inputs.

Our results are consistent with those from previous studies on SDA of changes of CO_2 emissions in China (Peng and Shi 2011; Zhang 2009), such as the important contribution from final demand and to the increase in CO_2 emissions and the compensating effect from improved energy intensity. However, we also obtained some novel findings. We found that energy intensity is the only driving factor contributing to the decrease of CO_2 emissions, whereas the Leontief effect and the sectoral structure effect, which decreased carbon intensity according to Zhang (2009), contributed to the increase of CO_2 emissions in this study. A second difference is that, by looking deeper into the Leontief effect, we found that the increase of the share of intermediate output is the main reason behind the contribution of the Leontief effect to the increase in emissions. Lastly, by analyzing the sectoral structure effect, we found that a shift to a more input-intensive product mix resulted in higher CO_2 emissions. By analyzing energy intensity in detail during the period of 2002–2005, we were able to interpret more comprehensively the fluctuation of energy intensity in this period than previous studies, such as Liao et al. (2007) and Ma and Stem (2008).

By further investigating the Leontief, sectoral structure, and demand allocation effects, we obtained more detailed information behind the increase of CO_2 emissions in China. First, we assessed with increased detail the changes in energy intensity. Second, we discovered a shift to a more input-intensive product mix, leading to an increase of intermediate output and to higher CO_2 emissions. Third, we discovered a positive correlation between high investment and high exports and CO_2 emissions. However, limitations still exist in this study. For instance, energy prices and income levels are two important factors which influenced CO_2 emissions and that are not included in this study, but actually, the two factors are analyzed indirectly as reasons of energy intensity decline and changes of demand allocation.

Efforts to reduce carbon emissions have been intensified. In its contribution for the conference of parties in Paris 2015, China promises to cut its greenhouse gas emissions per unit of GDP by 60–65 % from 2005 and to achieve a trend break (peak) in GHG emission before 2030.[3] The document states that "China will accelerate the transformation of energy production and consumption and continue to restructure its economy, optimize the energy mix, improve energy efficiency, and increase its forest carbon sinks, with a view to efficiently mitigating greenhouse gas emissions."[4] The share of coal is to be reduced and the shares of wind power and solar power are planned to increase to 200 and 100 GW, respectively (a doubling of the capacity for wind power and quadrupling of the capacity for solar power).[5] The closing down of old plants could be another alternative strategy based on the conclusion of this research on Leontief effect. This can be achieved by accelerating the process of marketization, encouraging the competition among enterprises, and ensuring a healthy business environment. Other—more difficult—strategies are to change the structure of the economy and reduce final demand. The last two options are the most challenging ones, as changing the sector structure is a complex, long-term affair and reductions in final demand conflict with the government's economic development goals. These options are therefore unlikely to be pursued for carbon reductions by Chinese authorities. China has developed strategies for increasing the share of renewable and nuclear energy sources in order to mitigate high levels of air pollution and is introducing policies for improving the energy efficiency of production. The

[3] China makes carbon pledge ahead of Paris climate summit, The Guardian, 30 June 2015.

[4] http://www4.unfccc.int/submissions/INDC/Published%20Documents/China/1/China's%20INDC%20-%20on%2030%20June%202015.pdf (p. 4)

[5] Ibid, p. 7.

share of consumption of final demand will probably increase, but expected growth rates in the order of 6 % or more in final demand will make it difficult for China to reduce its CO_2 emissions, which are therefore expected to rise in the coming years.

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