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The indirect energy consumption and CO_2 emission caused by household consumption in China: an analysis based on the input–output method

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ABSTRACT

In recent decades, China's rapid economy development has been coupling with the steadily increasing household consumption, which, in turn, leads to ever-growing energy consumption and CO_2 emission. With a focus on the decade of 2000–2010, this study examines the energy consumption and CO_2 emission caused by household consumption using the Input–Output method, as well as the influencing factors of the indirect CO_2 emission. The results show that, first, the indirect energy consumption and CO_2 emission appear the main parts of total energy consumption and CO_2 emission caused by household consumption, accounting for 69%–77% and 77%–84%, respectively. Second, the indirect CO_2 emission indicates an increasing trend mainly driven by per capita household consumption and energy intensity. Finally, the five sectors with relatively higher direct or total CO_2 emission intensity are the key sectors for reducing CO_2 emission in China, i.e., (1) Production and Distribution of Electric Power and Heat Power (PDEH), (2) Smelting and Pressing of Metals (SPM), (3) Processing of Petroleum, Coking, Processing of Nuclear Fuel (PPCPN), (4) Manufacture of Non-metallic Mineral Products (MNM), and (5) Manufacture of Chemical Materials (MCM).

1. Introduction

Since the beginning of the 21st century, China has been experiencing sustained and rapid economic development and improving urbanization level, which has led to the soaring of energy consumption (Yu et al., 2012). As China's energy consumption is dominated by coal consumption, the CO_2 emission in China has steadily increased in the past decade (Zhang et al., 2014). According to the statistics of BP (2014), China has become the world's largest CO_2 emitter since 2008, and the largest energy consumer since 2010. In 2013, China's energy consumption and CO_2 emission accounted for 22.4% and 27.1% of the globe, respectively. Similarly, the data of the Global Carbon Project sponsored by World Bank indicate that six countries, including China, United States, India, Russia, Japan and Germany, produced nearly 60% of global CO_2 emission in 2013, and China accounted for about 30% of global emission.[1] In this way, the planet's future will be shaped by what these top carbon emitters do about the heat-trapping gases blamed for global warming. Thus, as the largest developing country in the world, China is under great pressure from the international community to reduce energy consumption and CO_2 emission so as to address global climate change. Chinese government has since made gigantic and pragmatic efforts across the whole country in recent years. As documented in China's “Twelfth Five-Year Plan” (2011–2015), Chinese government sets energy conservation and CO_2 emission reduction as the pre-requisites for economic and social development, and hopes to cope with global climate change and realize sustainable development.

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[1] http://www.huffingtonpost.com/2014/12/05/a-handful-of-countries-co_n_6274064.html.

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Meanwhile, in recent years, China's central government has paid significant attention to the expansion of domestic consumption demand (particularly the household consumption demand) to strategically stabilize economic growth, and has been taking stimulating measures to wipe out the institutional obstacles. As a result, the analysis of energy consumption and CO_2 emission caused by household consumption has attracted much research attention from academia (Dai et al., 2012). In general, the energy consumption and CO_2 emission caused by household consumption include direct and indirect components. For instance, the direct CO_2 emission refers to that produced by direct energy consumption (such as cooking, warming, transportation), while the indirect CO_2 emission is that produced by the energy consumption of the products in their production, transportation, marketing and so on (Mongelli et al., 2006).

Most developed countries have seen that, during their developing process, the energy consumption of industrial production is the main source for CO_2 emission. However, according to recent statistical data from some developing countries, household energy consumption has exceeded industrial energy consumption since 1990s and become the main driver for the growing CO_2 emission (Zhu and Peng, 2012). China is of no exception, and China Energy Statistical Yearbook states that the direct energy consumption of Chinese households has increased from 133.2 million tonnes coal equivalent (tce) in 1985 to 396.7 million tce in 2012, with an annual average growth of 3.97% (NBSC, 2013a). In fact, most of the energy consumption and CO_2 emission caused indirectly by household consumption are in other goods consumed by households. In other words, the indirect energy consumption and CO_2 emission caused by household consumption are much higher than the direct counterparts. Nevertheless, the household energy consumption in China Energy Statistical Yearbooks only includes the direct energy consumption, which is used to calculate the corresponding direct CO_2 emission. Apparently, with the exclusion of indirect energy consumption, the total energy consumption and CO_2 emission caused by household consumption may be underestimated.

The main reason of that ignorance is due to the lack of scientific methods that can reasonably estimate the energy consumption and corresponding CO_2 emission indirectly caused by household consumption. Therefore, this paper proposes a methodology that leverages the Input–Output method to measure China's indirect energy consumption and CO_2 emission caused by household consumption during the period of 2000–2010. Moreover, with the complete decomposition analysis method, the proposed methodology explores the main influencing factors for the indirect CO_2 emission, not only from the national level but also from the sector level. Subsequently, this paper analyzes the direct and total CO_2 emission intensity among key carbon intensive sectors. Ultimately, this paper intends to provide effective policy suggestions to adjust the household consumption structure and realize the ambitious targets of energy conservation and CO_2 emission reduction for Chinese relevant governmental department.

The rest of this paper proceeds as follows. Section 2 reviews related literature. Section 3 describes the proposed data and provides the research methods. Subsequently, Section 4 presents the results and discussions, and finally, Section 5 concludes the paper together with some policy implications.

2. Relevant literature review

Controlling the CO_2 emission has been an important measure to alleviate global climate change. Researchers around the world have carried out a number of related studies, ranging from identifying the changing trends to recognizing the influencing factors of CO_2 emission, to investigating possible effective ways to win the co-existence of environmental protection and steady socio-economic development (Wang et al., 2012, 2015a; Ozturk and Acaravci, 2013; Ozturk et al., 2010; Acaravci and Ozturk, 2010; Zhang et al., 2014). In addition, numerous studies, such as Wyckoff and Roop (1994), Khrushch (1996) and Lenzen (1998), have shed light upon the embodied carbon leakage problem. The embodied carbon refers to carbon emitted in the production, transportation and marketing of products (including energy products). It should be noted that a great deal of literature pays close attention to carbon emission embodied in products consumed by the final demand.

Since the 1990s, many scholars have studied carbon embodied in international trade, which is a part of final demand, as seen from the Energy Balance Table. For instance, Shui and Harriss (2006) study the embodied carbon in Sino-US trade. The results show that embodied carbon emission growth rate is higher than that of Chinese carbon emission each year during 1997–2003 because of Chinese exports to the United States, and carbon dioxide emission of China's exports to USA is about 7%–14% of Chinese total carbon dioxide emission. Ahmad and Wyckoff (2003) find that China is the biggest country exporting carbon emission to OECD countries, and carbon emission caused by production is 10% more than that caused by consumption in China.

Among all final demand factors, the impact of household consumption on energy consumption and CO_2 emission has drawn significant attention in recent years. Literature has uncovered the energy consumption caused by household consumption, and more importantly, emphasized the indirect energy consumption accounting for a large proportion in the total energy consumption. For instance, Bin and Dowlatabadi (2005) argue that more than 80% of U.S. energy consumption is to meet consumer demand and to support related economic activities. Reinders et al. (2003) study the direct and indirect energy consumption arising from household consumption in 11 EU countries, and state that the indirect energy consumption accounts for 36%–66% of the total energy consumption with great differences from one country to another. Park and Heo (2007) investigate the energy consumption caused by household consumption in South Korea during 1980–2000 using the Input–Output method, which concludes that the energy consumption by households accounts for 52% of the national total energy consumption. Jane et al. (2008) detect the energy consumption and CO_2 emission by households on different household income levels in China, and argue that the indirect energy consumption by urban households accounts for 32% of the total household energy consumption. Furthermore, Wang and Shi (2009) reveal that the proportion of indirect energy consumption of urban households in their total household energy consumption increased from 69% in 1995 to 79% in 2004. Cellura et al. (2012) claim that indirect carbon emission caused by Italian household consumption has offset the improvement of environment by technological progress and environmental efficiency. Papathanasopoulou (2010) uses the input–output model to explore Greece's household consumption on fossil fuel and resulted carbon emission, and indicates that indirect energy consumption increased 60% from 1990 to 2006. It should be noted that the studies above imply that the main method estimating indirect energy consumption and CO_2 emission caused by household consumption is based on the input–output technique, which provides important reference for our study here.

In addition to the estimation of direct and indirect energy consumption and CO_2 emission, some literature further decomposes the influencing factors of CO_2 emission (Wang and Yang, 2013). The decomposition methods mainly belong to two categories: index decomposition analysis (IDA) method (Ang, 1995, 2004; Ang and Zhang, 2000; Liao et al., 2007) and structure decomposition analysis (SDA) method (Miller and Blair, 2009;

Kaivo-oja and Luukkanen, 2004; Wachsmann et al., 2009; Weber, 2009; Wood, 2009). SDA uses the input–output model to decompose changes in indicators while IDA uses only sectoral level data to research energy use and energy-related emissions. SDA has a more detailed analysis of technological and final demand effects while IDA has not. A detailed comparison of the two methods can be found in Hoekstra et al. (2003) and Su and Ang (2012).

The index decomposition analysis (IDA) method is usually used to decompose the direct CO_2 emission. For example, Lee and Oh (2006) decompose the CO_2 emission in the APEC countries and find that it is highly dependent on economic development level and population size. Zha et al. (2010) decompose the direct household CO_2 emission in China using IDA, and conclude that the main factors are energy intensity and income level. Wang et al. (2005) analyze the factors impacting CO_2 emission during 1957–2000 in China using the LMDI method, and argue that the reduction of energy intensity, as well as the use of alternative energy and renewable energy, can effectively decrease the CO_2 emission. One of the advantages of IDA is that it has lower data requirement. Its disadvantage, however, is also obvious. It is usually employed to decompose the direct CO_2 emission but not the indirect CO_2 emission because it cannot depict the input–output coefficient variations for CO_2 emission, which are captured by the Leontief inverse matrix (Mongelli et al., 2006; Tarancón and Del Río, 2007, 2012; Hoekstra et al., 2003).

In contrast, the structure decomposition analysis (SDA) method is mainly employed to decompose the indirect CO_2 emission caused by final demand and related factors, based on the Input–Output method. For example, Chang and Lin (1998) examine the indirect CO_2 emission of Taiwan during 1981–1991, and summarize that the final demand level and export growth are the primary promoting factors for the increase of indirect CO_2 emission, and energy intensity reduction proves the main curbing factor. Tarancón and Del Río (2007) decompose the indirect CO_2 emission caused by final demand and take into account three main influencing factors (i.e., direct consumption coefficient, final demand structure, and direct energy intensity) and ultimately find that final demand structure presents the maximum influencing magnitude. Furthermore, some literature decomposes the indirect CO_2 emission caused by household consumption in terms of final demand. For example, Paul and Bhattacharya (2004) dissemble the factors influencing the indirect CO_2 emission by household consumption in India during 1980–1996 into pollution index, energy intensity, household consumption structure, and household consumption level. The results show that household consumption level exerts the greatest influence. Similarly, Cellura et al. (2012) also study the indirect CO_2 emission caused by household consumption in Italy, and decompose the influencing factors into three categories: indirect CO_2 emission intensity, Leontief coefficient, and households' final demand.

Even though many previous studies usually find that China's indirect CO_2 emission is subject to numerous influencing factors (such as technological progress, household income, urbanization level, population size, and household consumption structure), they are unable to reveal the influence of energy substitution when the influencing factors are of concern (Zha et al., 2010; Yao et al., 2012; Liu et al., 2012). To solve this problem, this paper adopts the pollution index, based on Paul and Bhattacharya (2004), to represent CO_2 emission per unit of indirect energy consumption.

In addition, apart from the discussion about energy conservation and carbon emission reduction on the national level, there also have been many related studies on the sector level. It should be noted that sectors are not consistently divided due to different research needs, thus the results obtained may be of great variations. For example, Wyckoff and Roop (1994) analyze the influence of different sector classifications in 6 OECD countries on CO_2 emission, and reveal that there is more than 30% of difference in the influence between the two scenarios when 6 and 33 sectors are considered. Besides, Su et al. (2010) classify China's economy into 10 and 28 sectors to analyze the CO_2 emission embodied in trade and also find sharp differences based on different sector classifications. Similarly, Lenzen et al. (2004) develop the input–output model with sector levels varying from 39 to 133 sectors, and argue that the results of various sector levels are fairly different. Rodrigues and Domingos (2008) point out that carbon emission embodied in international trade is sensitive to the sector classification, and the finer the level of sector classifications is, the more accurate the decomposition results obtain.

Furthermore, at present, some literature focuses on CO_2 emission from energy consumption directly in the production process, ignoring energy consumption and thus embodied CO_2 emission of the other products consumed as intermediate inputs. Based on this, some scholars have begun to shed light upon the direct and total CO_2 emission intensity of sectors in China. For instance, Chen (2009) studies the embodied CO_2 emission from industrial processes, and considers that although some sectors have relatively lower direct CO_2 emission intensity, they should have undertaken relatively larger CO_2 emission because they consume a large number of CO_2 emission intensive products as intermediate inputs. However, existing studies have paid insufficient attention to such conditions. Therefore, with the detailed study on CO_2 emission intensity from the sector perspective, the results obtained by our study provide important information for policy makers to adjust household consumption structure and industrial structure in China.

To sum up, although previous literature has studied the indirect energy consumption and CO_2 emission caused by household consumption, there are still some shortcomings on the following aspects. (1) With respect to the decomposition methods, the commonly used IDA is only capable for direct CO_2 emission, but incapable for the indirect CO_2 emission decomposition analysis; (2) previous studies often fail to reflect energy substituting conditions when examining the influencing factors of CO_2 emission changes; (3) factors decomposition of CO_2 emission caused by household consumption in sector level is scarce; and (4) the direct and total CO_2 emission intensity of sectors have been rarely investigated in existing studies. Therefore, this paper may conduct some in-depth analyses to address these shortcomings.

3. Data and methods

3.1. Data definitions

The Input–Output coefficient and the household consumption are from the annually extended “Input–Output Table” from 2000 to 2010 from China Input–Output Association. The energy consumption by sector is from the “Consumption of Total Energy and Its Main Varieties by Sector” of China Energy Statistical Yearbook. The final energy consumption of industrial sectors used to calculate carbon emission is from the “Final Energy Consumption by Industrial Sector (Physical Quantity)” of China Energy Statistical Yearbook, and that of remaining sectors is from the “Energy Balance of China (Physical Quantity)” of China Energy Statistical Yearbook. It should be noted that the direct CO_2 emission of the PDEH sector is calculated by energy consumption consisting of the final energy consumption of the PDEH sector in “Final Energy Consumption by Industrial Sector (Physical Quantity)” and the input & output of transformation for Thermal Power and Heating Supply items in “Energy Balance of China (Physical Quantity)”.

The carbon emission factor is from the “2006 IPCC Guidelines for National Greenhouse Gas Inventories” of IPCC (2006). The conversion factors of energy from physical unit to coal equivalent, the calorific value per unit of coal equivalent, the producer price index (PPI) and the exchange rate of USD against Yuan (RMB) come from China Statistical Yearbook (2013). Producer Price Index-Commodities (USA) is from Bureau of Labor Statistics (BLS) of the US. Considering the different sector classifications in the economy between the Input–Output Table and China Energy Statistical Yearbook, this paper divides the economy into as many sectors as possible in order to get more accurate results. Therefore, following the method proposed by Su et al. (2010), this paper adopts the classification of 28 sectors in the economy, as shown in Appendix A.

In addition, when we calculate the carbon dioxide emission, 16 fossil energy sources are incorporated, i.e., raw coal, cleaned coal, other washed coal, coke, coke oven gas, other gas, other coking products, crude oil, gasoline, kerosene, diesel oil, fuel oil, liquefied petroleum gas, refinery gas, other petroleum products and natural gas. It should be noted that when we calculate the direct energy consumption of various sectors, the energy sources include electricity, but when the direct carbon dioxide emission of various sectors is calculated, electricity is not included, because the direct consumption of electricity does not produce carbon dioxide emission. The carbon dioxide emission by electricity consumption is calculated as the indirect carbon dioxide emission of each sector, and this part of carbon dioxide emission is transferred from the PDEH sector to other sectors.

3.2. Methods

(1) Estimating the indirect energy consumption caused by household consumption

According to Miller and Blair (1985), the basic input–output equation is as follows:

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

where the total output column vector $X = (X_1, X_2, X_3, ..., X_{28})^T$ and X_k is the output of sector k quoted in Yuan; I is the unit matrix; A stands for the direct consumption coefficient matrix; and $(I–A)^{-1}$ denotes the Leontief inverse matrix; the column vector of final demand $Y = (Y_1, Y_2, Y_3, ..., Y_{28})^T$ and Y_k is the final demand towards sector k quoted in Yuan.

For each of the 28 sectors in our study, R_k ($k = 1,2,...,28$) denotes the direct energy intensity of sector k (i.e., the direct energy consumption per unit of output, where direct energy consumption means energy consumed directly in the production of output in sector k), which is quoted in coal equivalent per Yuan and can be defined as Eq. (2).

$$R_k = \frac{E_k}{X_k} \tag{2}$$

where E_k denotes the direct energy consumption in sector k, quoted in coal equivalent. Thus, the row vector of direct energy intensity for all 28 sectors is $R = (R_1, R_2, R_3, ..., R_{28})$. Therefore, the sum of direct energy consumption of all sectors, i.e., E, can be estimated as Eq. (3).

$$E = RX = R(I - A)^{-1} Y \tag{3}$$

Similarly, we further calculate the total energy intensity of sector k, i.e., U_k. According to the Input–Output method (Das and Paul, 2014; Wang et al., 2014), the row vector of the total energy intensity for all 28 sectors can be constituted as follows:

$$U = (U_1, U_2, U_3, ..., U_{28}) = R \times (I - A)^{-1} \tag{4}$$

Meanwhile, due to the fact that the sum of direct energy consumption of all sectors is equivalent to the indirect energy consumption by final demand (Das and Paul, 2014; Wang et al., 2014), the indirect energy consumption caused by final demand in the economy can be also estimated as Eq. (5).

$$E = \sum_{k=1}^{28} U_k Y_k \tag{5}$$

Furthermore, in order to calculate the indirect energy consumption caused by household consumption which is part of final demand (sspecifically, from the structure of the Input–Output Table, we learn that the final demand includes capital formation and final consumption, and final consumption includes household consumption and government consumption.), we should replace Y_k with C_k, which is the household consumption on the products of sector k and quoted in Yuan, and the indirect energy consumption caused by household consumption by 28 sectors in the economy can be estimated as Eq. (6).

$$H = \sum_{k=1}^{28} H_k = \sum_{k=1}^{28} U_k C_k \tag{6}$$

where H_k is the indirect energy consumption caused by household consumption on the products of sector k and quoted in coal equivalent.

(2) Estimating the indirect carbon dioxide emission caused by household consumption

According to Wei et al. (2008) and Zhang and Da (2013), the calculation of carbon dioxide emission can be specified as Eq (7):

$$D_k = \sum_{i=1}^{16} d_{ki} = \sum_{i=1}^{16} e_{ki} \times f_i \times m_i \times \frac{44}{12} \times o_i \tag{7}$$

where D_k is the direct carbon dioxide emission produced by sector k; $_{dki}$ is the direct carbon dioxide emission caused by consumption of fossil energy source i by sector k; $_{dki}$ is the direct consumption of fossil energy source i in physical quantity by sector k; f_i is the calorific value per unit of fossil energy source i, and $f_i = g_i l$, where g_i is the conversion factor from physical unit to coal equivalent of fossil energy source i and l is the calorific value per unit of coal equivalent; m_i is the carbon emission per unit of calorific for consumption of fossil energy source i, i.e., the carbon emission factor; and o_i is the oxidation rate of fossil energy source i.

For the 28 sectors in our study, the direct carbon dioxide emission intensity of sector k, i.e., B_k, means the direct carbon dioxide emission per unit of output of sector k and is quoted in tonnes carbon dioxide emission per Yuan, where direct carbon dioxide emission implies carbon dioxide emission produced by energy consumed directly in the production of output of sector k. The direct carbon dioxide emission intensity can be written as Eq. (8), and the corresponding row vector of direct carbon dioxide emission intensity of sector k is $B = (B_1, B_2, B_3, ..., B_{28})$. Then, the sum of direct carbon dioxide emission of all sectors, i.e., D, can be estimated as Eq. (9).

$$B_k = \frac{D_k}{X_k} \tag{8}$$

$$D = BX = B(I - A)^{-1} Y \tag{9}$$

According to the Input–Output method, the row vector constituted by the total carbon dioxide emission intensity of all 28 sectors can be specified as Eq. (10).

$$F = (F_1, F_2, F_3, ..., F_{28}) = B \times (I - A)^{-1} \tag{10}$$

where F_k is the total carbon dioxide emission intensity of sector k. Because the sum of direct carbon dioxide emission of all sectors is equivalent to the indirect carbon dioxide emission by final demand (Das and Paul, 2014; Wang et al., 2014), the indirect carbon dioxide emission caused by final demand in the economy can also be estimated as Eq. (11).

$$D = \sum_{k=1}^{28} F_k Y_k \tag{11}$$

Finally, in order to calculate the indirect carbon dioxide emission caused by household consumption, we should replace Y_k with C_k, and estimate the indirect carbon dioxide emission from 28 sectors caused by household consumption as Eq. (12).

$$Q = \sum_{k=1}^{28} Q_k = \sum_{k=1}^{28} F_k C_k \tag{12}$$

where Q_k is the indirect carbon dioxide emission caused by household consumption on the products of sector k.

(3) The decomposition of indirect carbon dioxide emission caused by household consumption

The indirect carbon dioxide emission as mentioned in Eq. (12) can be decomposed into the following five types of effect as Eq. (13).

$$\begin{aligned} Q_k &= \frac{Q_k}{C_k} \times \frac{C_k}{\sum_{k=1}^{28} C_k} \times \frac{\sum_{k=1}^{28} C_k}{P} \times P \\ &= \frac{Q_k}{H_k} \times \frac{H_k}{C_k} \times \frac{C_k}{\sum_{k=1}^{28} C_k} \times \frac{\sum_{k=1}^{28} C_k}{P} \times P = W_k U_k S_k V P \end{aligned} \tag{13}$$

where $W_k = \frac{Q_k}{H_k}$, which means the carbon dioxide emission per unit of energy for sector k, i.e., the pollution coefficient; $U_k = \frac{H_k}{C_k}$, which indicates energy consumption per unit of household consumption on products of sector k, as shown in Eq. (6), i.e., the total energy intensity; $S_k = \frac{C_k}{\sum_{k=1}^{28} C_k}$, which implies the proportion of household consumption on the products of sector k in the total household consumption, i.e., the household consumption structure; and $V = \frac{\sum_{k=1}^{28} C_k}{P}$, i.e., the household consumption per capita and $P$is the population size.

Then, according to Sun (1998) and Das and Paul (2014), the contribution of the five effects to the changes of indirect carbon dioxide emission caused by household consumption on the products of sector k can be written as Eq. (14).

$$\Delta Q_k = \Delta Q_{W_k} + \Delta Q_{U_k} + \Delta Q_{S_k} + \Delta Q_{V_k} + \Delta Q_{P_k} \tag{14}$$

where ΔQ_{W_k} is the pollution effect on the changes of indirect carbon dioxide emission caused by household consumption on the products of sector k during 2000–2010, as shown in Eq. (15).

$$\begin{aligned} \Delta Q_{W_k} = {} & \sum_{k=1}^{28} \Delta W_k U_{k0} S_{k0} V_0 P_0 + \frac{1}{2} \sum_{k=1}^{28} \Delta W_k (\Delta U_k S_{k0} V_0 P_0 \\ & + U_{k0} \Delta S_k V_0 P_0 + U_{k0} S_{k0} \Delta V P_0 + U_{k0} S_{k0} V_0 \Delta P) \\ & + \frac{1}{3} \sum_{k=1}^{28} \Delta W_k (\Delta U_k \Delta S_k V_0 P_0 + \Delta U_k S_{k0} \Delta V P_0 \\ & + \Delta U_k S_{k0} V_0 \Delta P + U_{k0} \Delta S_k \Delta V P_0 + U_{k0} \Delta S_k V_0 \Delta P \\ & + U_{k0} S_{k0} \Delta V \Delta P) + \frac{1}{4} \sum_{k=1}^{28} \Delta W_k (\Delta U_k \Delta S_k \Delta V P_0 \\ & + \Delta U_k \Delta S_k V_0 \Delta P + \Delta U_k S_{k0} \Delta V \Delta P + U_{k0} \Delta S_k \Delta V \Delta P) \\ & + \frac{1}{5} \sum_{k=1}^{28} \Delta W_k \Delta U_k \Delta S_k \Delta V \Delta P \end{aligned} \tag{15}$$

ΔQ_{U_k} indicates the energy intensity effect on the changes of indirect carbon dioxide emission, as shown in Eq. (16).

$$\begin{aligned} \Delta Q_{U_k} = {} & \sum_{k=1}^{28} \Delta U_k W_{k0} S_{k0} V_0 P_0 + \frac{1}{2} \sum_{k=1}^{28} \Delta U_k (\Delta W_k S_{k0} V_0 P_0 \\ & + W_{k0} \Delta S_k V_0 P_0 + W_{k0} S_{k0} \Delta V P_0 + W_{k0} S_{k0} V_0 \Delta P) \\ & + \frac{1}{3} \sum_{k=1}^{28} \Delta U_k (\Delta W_k \Delta S_k V_0 P_0 + \Delta W_k S_{k0} \Delta V P_0 \\ & + \Delta W_k S_{k0} V_0 \Delta P + W_{k0} \Delta S_k \Delta V P_0 + W_{k0} \Delta S_k V_0 \Delta P \\ & + W_{k0} S_{k0} \Delta V \Delta P) + \frac{1}{4} \sum_{k=1}^{28} \Delta U_k (\Delta W_k \Delta S_k \Delta V P_0 \\ & + \Delta W_k \Delta S_k V_0 \Delta P + \Delta W_k S_{k0} \Delta V \Delta P + W_{k0} \Delta S_k \Delta V \Delta P) \\ & + \frac{1}{5} \sum_{k=1}^{28} \Delta W_k \Delta U_k \Delta S_k \Delta V \Delta P \end{aligned} \tag{16}$$

ΔQ_{S_k} stands for the household consumption structure effect on the changes of indirect carbon dioxide emission, as shown in Eq. (17).

$$\begin{aligned} \Delta Q_{S_k} = {} & \sum_{k=1}^{28} \Delta S_k U_{k0} W_{k0} V_0 P_0 + \frac{1}{2} \sum_{k=1}^{28} \Delta S_k (\Delta U_k W_{k0} V_0 P_0 \\ & + U_{k0} \Delta W_k V_0 P_0 + U_{k0} W_{k0} \Delta V P_0 + U_{k0} W_{k0} V_0 \Delta P) \\ & + \frac{1}{3} \sum_{k=1}^{28} \Delta S_k (\Delta U_k \Delta W_k V_0 P_0 + \Delta U_k W_{k0} \Delta V P_0 \\ & + \Delta U_k W_{k0} V_0 \Delta P + U_{k0} \Delta W_k \Delta V P_0 + U_{k0} \Delta W_k V_0 \Delta P \\ & + U_{k0} W_{k0} \Delta V \varDelta P) + \frac{1}{4} \sum_{k=1}^{28} \Delta S_k (\Delta U_k \Delta W_k \Delta V P_0 \\ & + \Delta U_k \Delta W_k V_0 \Delta P + \Delta U_k W_{k0} \Delta V \Delta P + U_{k0} \Delta W_k \Delta V \Delta P) \\ & + \frac{1}{5} \sum_{k=1}^{28} \Delta W_k \Delta U_k \Delta S_k \Delta V \Delta P \end{aligned} \tag{17}$$

ΔQ_{V_k} denotes the household consumption per capita effect on the changes of indirect carbon dioxide emission, as shown in Eq. (18).

$$\Delta Q_{V_k} = \sum_{k=1}^{28} \Delta V U_{k0} S_{k0} W_{k0} P_0 + \frac{1}{2} \sum_{k=1}^{28} \Delta V (\Delta U_k S_{k0} W_{k0} P_0 + U_{k0} \Delta S_k W_{k0} P_0 + U_{k0} S_{k0} \Delta W_k P_0 + U_{k0} S_{k0} W_{k0} \Delta P) + \frac{1}{3} \sum_{k=1}^{28} \Delta V (\Delta U_k \Delta S_k W_{k0} P_0 + \Delta U_k S_{k0} \Delta W_k P_0 + \Delta U_k S_{k0} W_{k0} \Delta P + U_{k0} \Delta S_k \Delta W_k P_0 + U_k \Delta S_k W_{k0} \Delta P + U_{k0} S_{k0} \Delta W_k \Delta P) + \frac{1}{4} \sum_{k=1}^{28} \Delta V (\Delta U_k \Delta S_k \Delta W_k P_0 + \Delta U_k \Delta S_k W_{k0} \Delta P + \Delta U_k S_{k0} \Delta W_k \Delta P + U_{k0} \Delta S_k \Delta W_k \Delta P) + \frac{1}{5} \sum_{k=1}^{28} \Delta W_k \Delta U_k \Delta S_k \Delta V \Delta P \tag{18}$$

and ΔQ_{P_k} implies the population effect on the changes of indirect carbon dioxide emission, as shown in Eq. (19).

$$\Delta Q_{P_k} = \sum_{k=1}^{28} \Delta P U_{k0} S_{k0} W_{k0} V_0 + \frac{1}{2} \sum_{k=1}^{28} \Delta P (\Delta U_k S_{k0} W_{k0} V_0 + U_{k0} \Delta S_k W_{k0} V_0 + U_{k0} S_{k0} \Delta W_k V_0 + U_{k0} S_{k0} W_{k0} \Delta V) + \frac{1}{3} \sum_{k=1}^{28} \Delta P (\Delta U_k \Delta S_k W_{k0} V_0 + \Delta U_k S_{k0} \Delta W_k V_0 + \Delta U_k S_{k0} W_{k0} \Delta V + U_{k0} \Delta S_k \Delta W_k V_0 + U_{k0} \Delta S_k W_{k0} \Delta V + U_{k0} S_{k0} \Delta W_k \Delta V) + \frac{1}{4} \sum_{k=1}^{28} \Delta P (\Delta U_k \Delta S_k \Delta W_k V_0 + \Delta U_k \Delta S_k W_{k0} \Delta V + \Delta U_k S_{k0} \Delta W_k \Delta V + U_{k0} \Delta S_k \Delta W_k \Delta V) + \frac{1}{5} \sum_{k=1}^{28} \Delta W_k \Delta U_k \Delta S_k \Delta V \Delta P \tag{19}$$

4. Results and discussions

4.1. The energy consumption and CO_2 emission caused by household consumption

Based on Eqs. (6) and (12), this paper finds that, on the one hand, the sum of direct and indirect energy consumption caused by household consumption accounts for 40% of the total energy consumption in China on average during 2000–2010, while the CO_2 emission caused by household consumption accounts for 41% of the total on average, which are shown in Fig. 1 and basically in accordance with the results by Liu et al. (2011). These findings suggest that neither the direct nor indirect energy consumption and CO_2 emission caused by household consumption can be neglected, which would otherwise underestimate the energy consumption and carbon emission demand projections in China; meanwhile, neglecting either of them can potentially add difficulty in achieving the targets for energy conservation and carbon emission reduction. According to Fig. 1, the following results can be captured:

(1) The direct energy consumption and CO_2 emission caused by household consumption increase year-by-year. During 2000–2010, the direct energy consumption by household consumption increased 121%, from 156 million tonnes coal equivalent up to 346 million tonnes coal equivalent. The direct CO_2 emission caused by household consumption rose 163%, from 319 million tonnes carbon dioxide emission in 2000 to 838 million tonnes carbon dioxide emission in 2010.

(2) The indirect energy consumption and CO_2 emission caused by household consumption experience an overall increase despite a short-lived decline, which are mainly attributed to the influence of per capita household consumption increase. Specifically, China's per capita household consumption rose 148% from 2000 to 2010, which drives the forceful growth of energy consumption and corresponding CO_2 emission.

(3) The indirect energy consumption and CO_2 emission are the main sources for energy consumption and CO_2 emission caused by household consumption, respectively. Specifically, the indirect energy consumption and CO_2 emission caused by household consumption during 2000–2010 were 2.2–3.4 times and 3.4–5.3 times of their direct counterparts, respectively, and 69%–77% and 77%–84% of total energy consumption and CO_2 emission caused by household consumption, respectively. These results echo with that by Reinders et al. (2003), which indicates that the direct energy consumption caused by household consumption in 11 European countries merely accounts for 35% of total energy consumed by households, much lower than that of the indirect component.

4.2. The decomposition of indirect CO_2 emission caused by household consumption

To better control CO_2 emission, this study investigates the variation of indirect CO_2 emission caused by household consumption during 2000–2010. The influencing factors considered here include pollution index, energy intensity, household consumption structure, per capita household consumption and population size (see Fig. 2). The following findings are obtained.

(1) Among the five key factors as aforementioned, the increase of per capita household consumption plays the most important role in promoting indirect CO_2 emission. During 2000–2010, the indirect CO_2 emission caused by household consumption increased 164% due to the 146% of growth of per capita household consumption, from 3496 Yuan per person in 2000 up to 8590 Yuan per person in 2010, i.e., from 422 USD per person up to 912 USD per person, with the exchange rate of USD against Yuan and the PPI (USA) shown in Appendix B. This attributes to the fact that the rapid economic development during this period greatly spurred the steady growth of household consumption (Zhang, 2011). Similar case has been found in India. For instance, Paul and Bhattacharya (2004) decompose the influencing factors for the indirect CO_2 emission caused by household consumption during 1980–1996 in India, and also find that economic growth serves as the main factor for the growth of indirect CO_2 emission caused by household consumption during that period.

(2) Energy intensity decrease appears as the main curbing factor to inhibit the growth of indirect CO_2 emission caused by household consumption. Owing to total energy intensity decrease by 44% from 193 tonnes coal equivalent per million Yuan in 2000 down to 107 tonnes coal equivalent per million Yuan in 2010, i.e., from 1.6 tonnes coal equivalent per thousand USD down to 1.0 tonnes coal equivalent per thousand USD, the indirect CO_2 emission declined by 126%. Similarly, Paul and Bhattacharya (2004) argue that the decrease of energy intensity plays an important role in reducing the indirect CO_2 emission caused by household consumption in India.

(3) The influence of pollution index, household consumption structure and population size on the indirect CO_2 emission

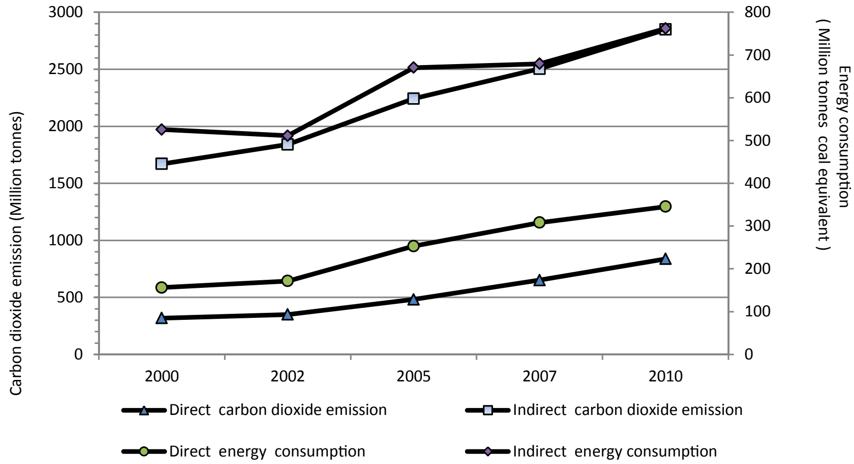

Fig. 1. Energy consumption and carbon dioxide emission caused by household consumption during 2000–2010 (This figure generates from our estimates).

caused by household consumption appears to be relatively weaker. This finding is not consistent with those by some previous literature. For instance, the results by Zhao et al. (2012) on the urban household energy consumption in China during 1998–2007 suggest that population growth acts as the main cause for the urban household energy consumption increase. Additionally, Wang et al. (2015b) decompose the indirect CO_2 emission caused by household consumption in China during 1992–2007, and point out that household consumption level improvement, household consumption structure changes, and population growth all significantly promote the rising indirect CO_2 emission. The difference can be explained from at least three aspects. ① Their sample periods are different; ② they employ different decomposition methods, and the influence of residuals is varying; and ③ they use different sector aggregating methods; specifically, Wang et al. (2015b) aggregate all the economic industries into 22 sectors, while we take the 28 sector classification. Another thing should be noted that the effect of household consumption structure on carbon dioxide changes is negative from 2007 to 2010, which in fact indicates the transmission of people's consumption patterns; specifically, they tend to be more low-carbon due to the increase of affordability and awareness of environmental protection and health, which may be discussed in detail below.

4.3. The indirect CO_2 emission from key carbon intensive sectors and its decomposition

The variations of indirect CO_2 emission from 2000 to 2010 caused by household consumption among the 28 sectors are shown in Table C of Appendix C. From Table C, we single out 14 sectors with relatively higher indirect CO_2 emission and larger changes of indirect CO_2 emission caused by household consumption from 2000 to 2010. Figs. 3 and 4 show the indirect energy consumption and CO_2 emission caused by household consumption on the products of the 14 sectors based on Eqs. (6) and (12). Fig. 5 shows the factor decomposition of indirect carbon dioxide emission produced by these 14 sectors and some results are obtained as follows:

(1) The indirect energy consumption and CO_2 emission caused by household consumption on the FFAF sector products presents a year-by-year decreasing trend, down from 79 million tonnes coal equivalent and 238 million tonnes in 2000 to 43 million tonnes coal equivalent and 134 million tonnes in 2010, respectively. The reasons for such decrease are mainly twofolds. On the one hand, the rise of biological low-carbon agriculture reduces the utilization of pesticide and fertilizer, and meanwhile, agricultural straw burning is strictly controlled. On the other hand, household consumption on the products of sector FFAF declines from 1096 billion

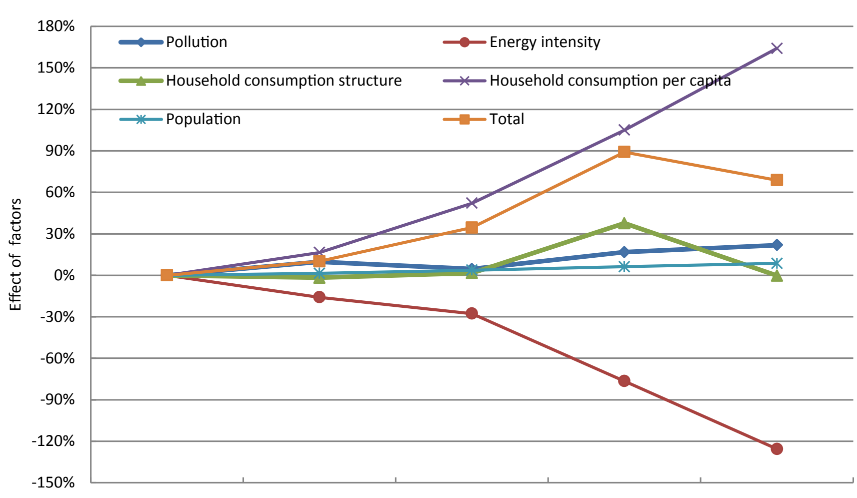

Fig. 2. The effect decomposition of indirect carbon dioxide emission caused by household consumption during 2000–2010. (This figure generates from our estimate).

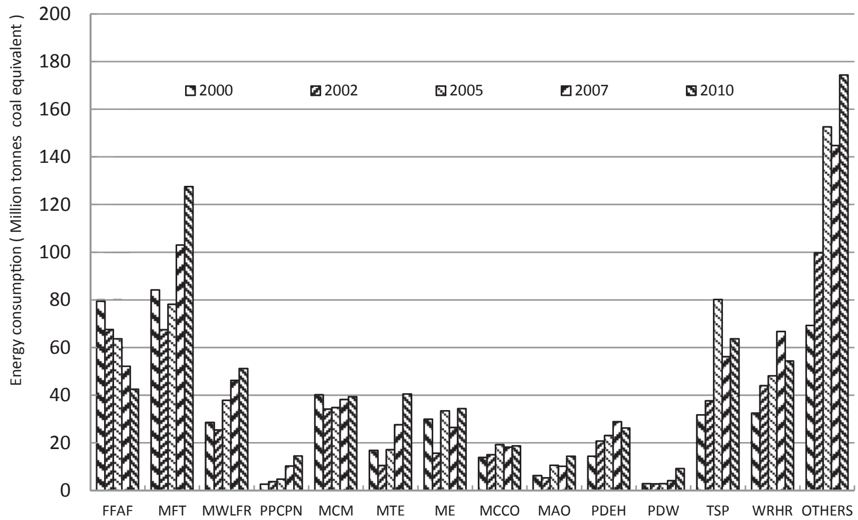

Fig. 3. The indirect energy consumption caused by household consumption on the products of key carbon intensive sectors during 2000–2010. The sector name abbreviations in the horizontal axis can be found in Appendix A. (This figure generates from our estimate).

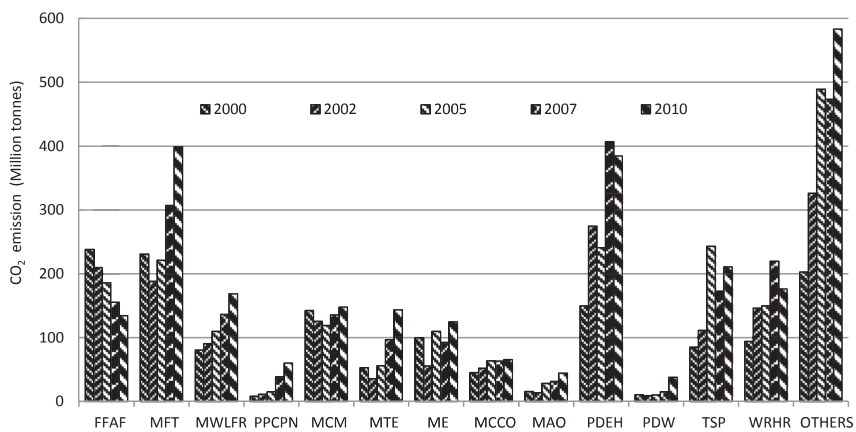

Fig. 4. The indirect carbon dioxide emission caused by household consumption on the products of key carbon intensive sectors during 2000–2010. The sector name abbreviations in the horizontal axis can be found in Appendix A. (This figure generates from our estimate).

Yuan in 2000 to 977 billion Yuan in 2010, i.e., from 132 billion USD down to 104billion USD (NBSC, 2013b).

(2) The indirect energy consumption and CO_2 emission caused by household consumption on the products of the other 13 sectors experiences a year-by-year increasing trend; therein, the indirect CO_2 emission caused by household consumption on the products of the OTHERS sector ranks the top, followed by PDEH, MFT, FFAF, TSP, WRHR and MCM in sequence.

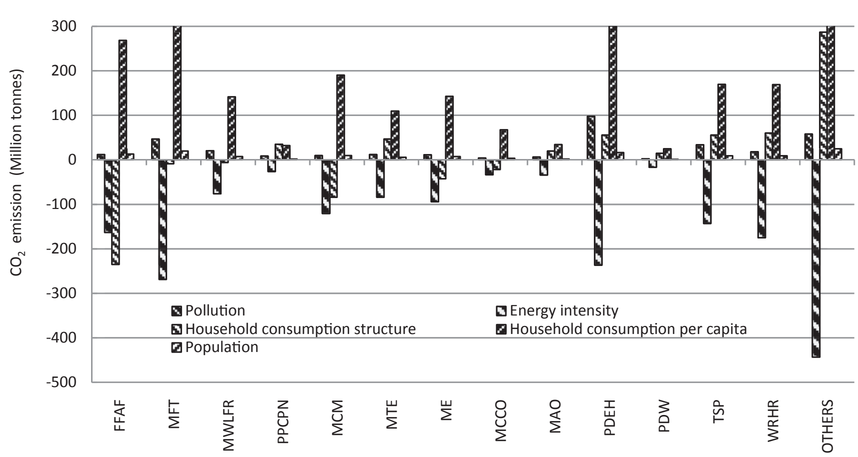

Fig. 5. The effect decomposition of indirect carbon dioxide emission caused by household consumption on the products of some key sectors from 2000 to 2010. The sector name abbreviations in the horizontal axis can be found in Appendix A. (This figure generates from our estimate).

Specifically, during 2000–2010, the household consumption on the products of these sectors resultd in indirect CO_2 emission of 415, 291, 269, 185, 165,157 and 134 million tonnes carbon dioxide emission on average, respectively. Thus, they are the key sectors for carbon emissions reduction in China. It should be noted that the indirect energy consumption embodied in household consumption for sector PDEH is not large but it has a high indirect CO_2 emission. As we know, electricity does not produce CO_2 emission directly when consumed. In order to avoid repeated calculation, the input & output of transformation for Thermal Power and Heating Supply items in "Energy Balance of China (Physical Quantity)" is not calculated when getting indirect energy consumption caused by household consumption for sector PDEH. However, it is calculated when the indirect CO_2 emission caused by household consumption for sector PDEH is concerned, because it produces CO_2 emission in the production process of electricity. Similarly, Alcántara and Padilla (2003) point out that the sectors including transport, chemistry, steel and food are the key ones for the indirect energy consumption caused by final demand in Spain. The reason for the high emission in these sectors in our study mainly includes high household consumption, high carbon emission intensity etc. For example, the OTHERS sector (including sectors "Finance and Insurance Industry", "Real Estate", "Education", "Health, Social Security and Social Welfare Projects" etc.) is an important part of the Tertiary industry and closely with the households and their consumption in this sector is relatively higher; specifically, 31% of total household consumption in 2010 (please see Appendix D for the household consumption of sectors in 2010). Besides, the total carbon emission intensity of the OTHERS sector appears high, because this sector is closely related to other sectors and the consumption of other industries is partly driven by its product consumption. For example, in the sector "Education" in OTHERS, the facilities and books needed by educational activities are supplied by other sectors, such as, sectors MPPA and MCCO. Therefore, its embodied indirect carbon emissions are fairly higher.

Then, based on Eqs. 15–19, this paper decomposes the changes of indirect carbon dioxide emission produced by a single sector into 5 types of effect, including pollution index, energy intensity, household consumption structure, per capita household consumption and population size. The results are shown in Fig. 5, and several findings are acquired as follows.

(1) The increase of per capita household consumption is always the main factor for the increase of indirect CO_2 emissions caused by household consumption on the products of various sectors, among which the OTHERS, MFT, PDEH, FFAF, MCM, TSP and WRHR sectors are influenced most. From 2000 to 2010, the indirect CO_2 emission influenced by the increase of per capita household consumption on the products of these seven sectors increased 4.53, 3.79, 3.01, 2.69, 1.90, 1.70 and 1.69 tonnes carbon dioxide emission, respectively.

(2) The reduction of energy intensity, namely, the improvement of energy efficiency and technology, significantly decreases the indirect CO_2 emission caused by household consumption on the products of fourteen sectors, among which six sectors exert the most significant influence, i.e., OTHERS, MFT, PDEH, WRHR, FFAF and TSP sectors. From 2000 to 2010, the indirect CO_2 emission influenced by the total energy intensity reduction of these six sectors decreased by 4.43, 2.69, 2.36, 1.75, 1.63 and 1.43 tonnes carbon dioxide emission, respectively, owing to the 45% reduction of total energy intensity of these six sectors from 126 tonnes coal equivalent per million Yuan down to 69 tonnes coal equivalent per million Yuan on average, i.e., from 1043 tonnes coal equivalent per million USD down to 650 tonnes coal equivalent per million USD on average. India has similar situation, as Paul and Bhattacharya (2004) point out that the decline of energy intensity in India during 1980–1996 acted as the main factor for the reduction of indirect CO_2 emission caused by household consumption.

(3) The consumption behavior inclination of people gradually transfers from the survival-oriented pattern towards the development-oriented and leisure-oriented patterns. In fact, according to the report in People's Daily in China, along with the continuous increase of people's income, the household consumption structure has upgraded along the evolving path from clothing and food, shelter and means of traveling, towards leisure and recreation. As a result, the expenditure proportions of healthcare, leisure and other emerging modern life services have ushered in the outbreak period.[2] From the year of 2000–2010, the household consumption on the products of survival sectors, comprising FFAF and MFT, in the total household consumption was reduced by 16% and 1.3%, respectively, which caused the indirect CO_2 emission of these sectors for the factor of household consumption structure to decline, as shown in Fig. 5. Meanwhile, the proportions of household consumption on product of development-oriented and leisure-oriented sectors, including TSP, WRHR and OTHERS, in the total household consumption were increased by 1.6%, 3.6%, and 15.7%, respectively. Consequently, the indirect CO_2 emission of these sectors for household consumption structure factor has increased (see Fig. 5). Spain has seen similar situation. For instance, Tarancón and Del Río (2007) find that the fuel improvement technology in transport sector in Spain reduces the indirect CO_2 emission caused by final demand; however, such reduction is offset by the CO_2 emission caused by the final demand increase in transport sector.

(4) Pollution index and population size exert insignificant influence on all the 14 sectors in terms of the indirect CO_2 emission caused by household consumption. Previous studies on the influencing factors of China's CO_2 emission also have achieved similar conclusions. For example, Zhu and Peng (2012) investigate the influencing factors for China's CO_2 emission and suggest that population size exerts little effect on CO_2 emission.

4.4. Comparison of the direct and total CO_2 emission intensity among key sectors

Fig. 6 Illustrates the comparison results of the direct and total CO_2 emission intensity of the 28 sectors mentioned above and Fig. 7 further illustrates the comparison results of the direct and total CO_2 emission in 28 sectors caused by household consumption in 2010, which are calculated by the direct and total CO_2 emission intensity multiply by household consumption, respectively. The following findings are identified.

(1) The top seven sectors with higher direct CO_2 emission intensity include PDEH, SPM, PPCPN, MNM, MCM, TSP and MWC. Similarly, Zhu et al. (2012) state that MWC, PPCPN, SPM sectors have been those with highest CO_2 emission intensity in China in 2005. The sectors with higher CO_2 emission intensity

[2] http://he.people.com.cn/n/2014/0903/c192235-22201526.html.

basically keep unchanged from 2000 to 2010. In recent years, China has eliminated a great deal of backward production capacity and vigorously promoted the strategic emerging industries to control CO_2 emission from these sectors.

(2) The top seven sectors with higher total CO_2 emission intensity comprise PDEH, SPM, MM, MNM, MCM, PPCPN and PDW, and total CO_2 emission for sectors PDEH, MCM and PPCPN caused by household consumption is large, as can be seen from Fig. 7, due to much household consumption on the products of these sectors. Although sectors SPM and MNM do not have large total CO_2 emission, they show larger direct CO_2 emission intensity. Sectors MM and PDW do not have large total CO_2 emission, and they also show the lower direct CO_2 emission intensity. So these five sectors including PDEH, SPM, MNM, MCM and PPCPN are the key sectors for energy conservation and emission reduction in China.

(3) Some sectors have relatively lower direct CO_2 emission intensity while higher total CO_2 emission intensity, including MM, PDW, ME, MPM and MGSM. The main reason lies in that the production in these sectors highly depends on the products of carbon intensive sectors as the intermediate inputs, but the total CO_2 emission for sectors MM, PDW, MPM and MGSM caused by household consumption is relatively fewer, as shown in Fig. 7, due to little household consumption on the products of these sectors, so they are not important as sector ME in control of carbon emission. With respect to sector ME, it has to accelerate the replacement of CO_2 intensive intermediate inputs with clean and environment friendly products, so as to slow down its CO_2 intensity.

5. Conclusions and policy implications

5.1. Main conclusions

This study proposes the Input–Output method to measure the direct and indirect CO_2 emission caused by household consumption, decomposes the influencing factors for the indirect CO_2 emission, and analyzes the direct and total CO_2 emission intensity among key carbon intensive sectors during 2000–2010 in China. The main conclusions are soundly drawn as follows.

(1) The indirect energy consumption and CO_2 emission caused by household consumption accounts for 69%–77% and 77%–84% of their corresponding totals, respectively. That means the energy consumption and carbon emission caused by household consumption is mainly achieved by consuming the products. In 2010, the energy consumption and CO_2 emission caused by household consumption accounted for 40% and 41% of the total energy consumption and CO_2 emission in China, respectively. Thus, neither of them can be neglected for implementing energy conservation and carbon emission reduction strategies.

(2) Overall, the indirect CO_2 emission caused by household consumption presents an increasing trend. The increase of per capita household consumption and improvement of energy intensity act as the primary influencing factors for indirect CO_2 emission caused by household consumption. Therein, the sectors, such as OTHERS, MFT, PDEH, WRHR, FFAF and TSP, are most affected by both factors, which are the key sectors need to be paid attention to. Besides, the behavior preference of household consumption in China has transformed from the survival-oriented pattern to the development-oriented and the leisure-oriented patterns. Therefore, it is of great importance to encourage rational consumption and improve the household consumption structure so as to promote low-carbon lives in China.

(3) The sectors with higher direct or total CO_2 emission intensity, including PDEH, SPM, MNM, MCM and PPCPN should be paid great attention to reducing CO_2 emission in China. Meanwhile, sector ME presents lower direct CO_2 emission intensity while higher total CO_2 emission intensity, and should accelerate the use of clean and environment friendly products as the intermediate products.

5.2. Policy implications

The results above indicate that the energy consumption and CO_2 emission caused by household consumption, especially the indirect components, have accounted for relatively larger proportions in the total in the past decade in China. Therefore, when projecting the energy consumption demand and carbon emission demand which are of concern in China, we cannot only consider the influence of economic growth as usual; when policies are made to cut China's energy intensity and carbon emission intensity in the near future, we should not only reckon on the relationship adjustment among economic growth, energy consumption and carbon emission, as often suggested by previous literature. The role of household consumption in reducing energy conservation and carbon emission has to be understood. Otherwise, the real energy consumption and carbon emission will be underestimated, and it will be very challenging to realize China's

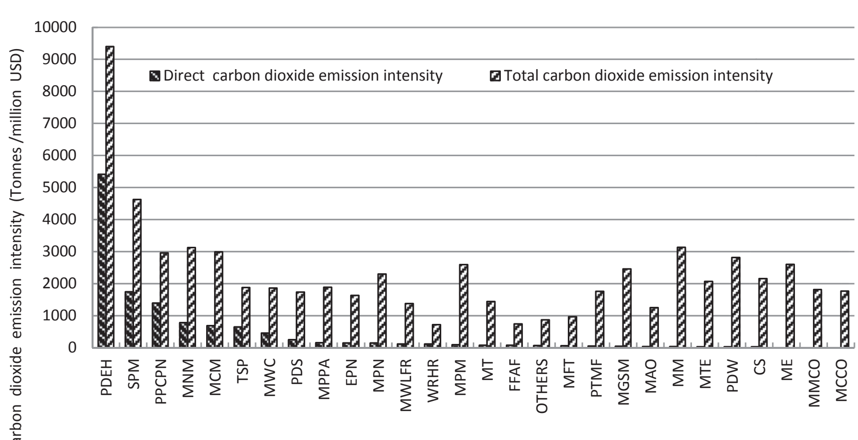

Fig. 6. The direct and total carbon dioxide emission intensity of 28 sectors in 2010. The abbreviations of the sectors in the horizontal axis can be found in Appendix A. The Producer Price Index (USA) here is based on the year of 2010. (This figure generates from our estimate).

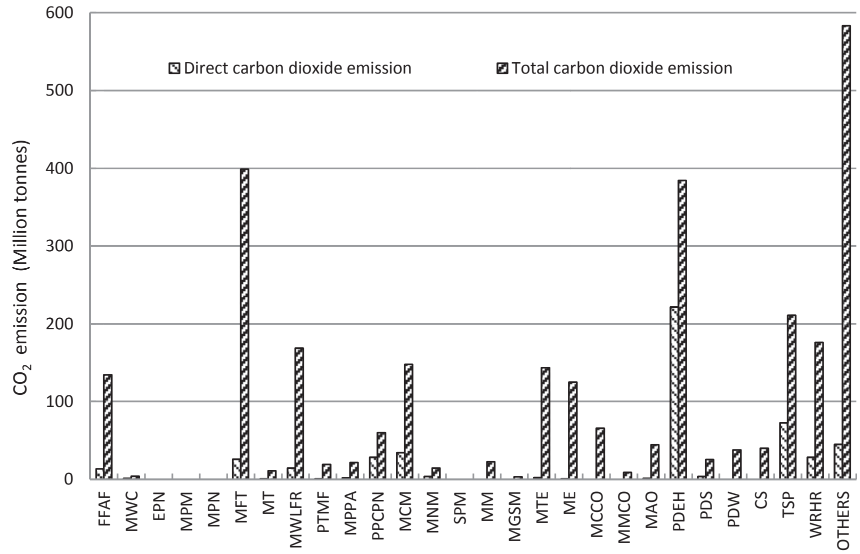

Fig. 7. The direct and total carbon dioxide emission of 28 sectors caused by household consumption in 2010. The abbreviations of the sectors in the horizontal axis can be found in Appendix A. (This figure generates from our estimate).

targets of reducing 16% energy intensity and 17% carbon emission intensity during the 12th Five-Year Plan period (2011–2015), and reducing 40%–45% carbon emission intensity by 2020 compared with the 2005 level. Besides, the results imply that adjusting the economic and consumption structure and improving efficiency should be adopted by China's government to achieve the targets of energy conservation and emission reduction when expanding domestic consumption. Specifically, according to the research results in this study, the following policy implications worth to be considered by Chinese government and carbon-intensive sectors or enterprises.

(1) By way of incentive guidance on publics and support on new energy enterprises, the government should consistently guide rational household consumption, improve household energy consumption structure, advocate new energy policies, encourage the utilization of environment friendly products, promote the products of new energy enterprises with the opportunities of "15th March" (i.e., the World Consumer Right Day), formulate certain preferential policies for new energy enterprises, and encourage people and related enterprises to consciously use low-carbon products. Household should reduce the consumption on products of these sectors with high total CO_2 emission intensity.
(2) Through industrial policy adjustment and technology import, the government should promote the upgrade and transformation of the sectors with higher CO_2 emission intensity. On the one hand, Chinese government should continue to enhance the development and transformation of sectors with excess capacity by way of subsidies and taxes. Energy intensity decrease appears as the main curbing factor to inhibit the growth of indirect CO_2 emission caused by household consumption, therefore, it is required to reorganize and optimize existing higher energy-consuming sectors and resolutely cancel low-efficient and high energy-consuming projects. On the other hand, the government is expected to strengthen the policy inclination to high technology import in energy exploration and exploitation and encourage low-carbon technology investment of related enterprises.
(3) Chinese government needs to shape some stimulating economic and tax policies to guide related carbon-intensive sectors and enterprises to actively promote the use of renewable energy, such as solar energy, and advocate the large-scale application of solar thermal systems in industry, public institutions, commercial and household lives.
(4) Chinese government is expected to strengthen the construction of low-carbon society, develop low-carbon community and promote low-carbon lifestyles. Specifically, the government is supposed to advocate the construction of energy-efficient buildings, the extensive use of new energy vehicles and the popularization of green traffic. For instance, according to the Suzhou Daily, the city of Suzhou in Jiangsu province of China has launched a plan of public bicycles since August 2010, and by the end of 2014, over 500 thousand citizens have traveled by bicycle. As a result, 3800 tonnes carbon emission could be decreased in one year.[3]

It should be noted that it is a tough and long-term work to reduce energy use and CO_2 emission in China, and there is a great amount of future work to be done to achieve such goals. For instance, this study has not considered the influence of population structure (such as different income groups) on indirect CO_2 emission caused by household consumption. Meanwhile, the social cultural features and income level of households can be investigated in the future when decomposing CO_2 emission caused by household consumption.

Acknowledgments

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Appendix A. Sector aggregation

1. The sector aggregation in the "Input–Output Table"

The sectors in Input–Output Table in 2007 are essentially consistent with that in 2002 except the following sectors. "Tourism" is included in Input–Output table in 2002 not in 2007. "Water conservancy, environment and public facilities management industry" is in Input–Output Table in 2007, but not in 2002. These two sectors both belong to "Other Service Industry", so they

[3] http://news.subaonet.com/2014/1208/1426956.shtml.

are both retained in ”Other”. The other sectors are the same, and they are aggregated into the following:

(1) “Manufacture of Artwork and Other Manufacturing (Including Recycling and Disposal of Waste)” is aggregated by “Manufacture of Artwork and Other Manufacturing” and “Recycling and Disposal of Waste”.
(2) “Transport, Storage and Post” is aggregated by “Transport and Storage”, “Post” and “Information Transmission, Computer Services and Software”.
(3) “Wholesale, Retail Trade and Hotel, Restaurants” is aggregated by “Wholesale and Retail Trade” and “Hotel and Restaurants”.
(4) “Others” is aggregated by “Finance and Insurance Industry”, “Real Estate”, “Leasing and Business Service”, “Scientific Investigation”, “Integrated Technological Services”, “Other Social Services”, “Education”, “Health, Social Security and Social Welfare Projects”, “Culture, Sports and Entertainment” and “Public Administration and Social Organizations”.

In the end, the number of aggregated sectors in the “Input–Output Table” arrives at 28, which are consistent with the sectors in the “Energy Balance of China” as follows.

2. The sector aggregation in the “Energy Balance of China”

(1) “Mining and Processing of Metal Ores” is aggregated by “Mining and Processing of Ferrous Metal Ores” and “Mining and Processing of Non-Ferrous Metal Ores”, while the “Mining of Other Ores” is deleted.
(2) “Manufacture of Foods and Tobacco” is aggregated by “Processing of Food from Agricultural Products”, “Manufacture of Foods”, “Manufacture of Beverages” and “Manufacture of Tobacco”.
(3) “Manufacture of Wearing Apparel, Leather, Feather and Related Products” is aggregated by “Manufacture of Textile Wearing Apparel, Footwear and Caps” and “Manufacture of Leather, Fur, Feather and Related Products”.
(4) “Processing of Timber, Manufacture of Furniture” is aggregated by “Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm and Straw Products” and “Manufacture of Furniture”.
(5) “Manufacture of Paper, Printing and Articles For Culture, Education and Sport Activity” is aggregated by “Manufacture of Paper and Paper Products”, “Printing, Reproduction of Recording Media” and “Manufacture of Articles For Culture, Education and Sport Activity”.
(6) “Manufacture of Chemical Materials” is aggregated by “Manufacture of Raw Chemical Materials and Chemical Products”, “Manufacture of Medicines”, “Manufacture of Chemical Fibers”, “Manufacture of Rubber” and “Manufacture of Plastics”.
(7) “Smelting and Pressing of Metals” is aggregated by “Smelting and Pressing of Ferrous Metals” and “Smelting and Pressing of Non-ferrous Metals”.
(8) “Manufacture of General and Special Purpose Machinery” is aggregated by “Manufacture of General Purpose Machinery” and “Manufacture of Special Purpose Machinery”.
(9) “Manufacture of Artwork and Other Manufacturing (Including Recycling and Disposal of Waste)” is aggregated by “Manufacture of Artwork and Other Manufacturing” and “Recycling and Disposal of Waste”.

As a result, the number of aggregated sectors in the “Energy Balance of China” also reaches 28, which corresponds to sectors in the “Input–Output Table” above.

3. The 28 sectors in this paper[a] and their abbreviations

Table A
The name abbreviations of 28 sectors concerned in this paper.[a]

No.	Sector	Name abb.
1	Farming, Forestry, Animal Husbandry, Fishery and Water Conservancy	FFAF
2	Mining and Washing of Coal	MWC
3	Extraction of Petroleum and Natural Gas	EPN
4	Mining and Processing of Metal Ores	MPM
5	Mining and Processing of Nonmetal Ores	MPN
6	Manufacture of Foods and Tobacco	MFT
7	Manufacture of Textile	MT
8	Manufacture of Wearing Apparel, Leather, Feather and Related Products	MWLFR
9	Processing of Timber, Manufacture of Furniture	PTMF
10	Manufacture of Paper, Printing and Articles For Culture, Education and Sport Activity	MPPA
11	Processing of Petroleum, Coking, Processing of Nuclear Fuel	PPCPN
12	Manufacture of Chemical Materials	MCM
13	Manufacture of Non-metallic Mineral Products	MNM
14	Smelting and Pressing of Metals	SPM
15	Manufacture of Metal Products	MM
16	Manufacture of General and Special Purpose Machinery	MGSM
17	Manufacture of Transport Equipment	MTE
18	Manufacture of Electrical Machinery and Equipment	ME
19	Manufacture of Communication Equipment, Computers and Other Electronic Equipment	MCCO
20	Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work	MMCO
21	Manufacture of Artwork and Other Manufacturing(Including Recycling and Disposal of Waste)	MAO
22	Production and Distribution of Electric Power and Heat Power	PDEH
23	Production and Distribution of Gas	PDS
24	Production and Distribution of Water	PDW
25	Construction	CS
26	Transport, Storage and Post	TSP
27	Wholesale, Retail Trade and Hotel,Restaurants	WRHR
28	Others	OTHERS

[a] This table generates from “Input–Output Table” and China Energy Statistical Yearbook.

Appendix B. Conversion coefficients

Table B.1
Exchange rate of USD against Yuan.[a]

Year	Exchange rate of 100 USD against Yuan (Yuan)
2000	827.84
2002	827.70
2005	819.17
2007	760.40
2010	676.95

[a] Data come from NBSC (2013b).

Table B.2
Producer price index-Commodities (USA).[a]

Year	Annual producer price Index-Commodities (base year:1982 = 100)
2000	132.7
2002	131.1
2005	157.4
2007	172.6
2010	184.7

[a] Data come from NBSC (2013b).

Table B.3
Producer price index (China).[a]

Year	Annual producer price Index (base year:1985 = 100)
2000	303.1
2002	292.6
2005	333.2
2007	353.8
2010	377.5

[a] Data come from NBSC (2013b).

Appendix C. Indirect CO_2 emission changes

Table C
The changes of indirect carbon dioxide emission caused by household consumption on the products of 28 sectors from 2000 to 2010.[a]

No.	Sector	CO_2 emission in 2000 (million tonnes carbon dioxide emission)	CO_2 emission in 2010 (million tonnes carbon dioxide emission)	Change (million tonnes carbon dioxide emission)	Change (%)
1	Farming, Forestry, Animal Husbandry, Fishery and Water Conservancy	238.19	134.30	−103.89	−43.62
2	Mining and Washing of Coal	5.42	3.77	−1.66	−30.55
3	Extraction of Petroleum and Natural Gas	1.10	0.00	−1.10	−100.00
4	Mining and Processing of Metal Ores	0.00	0.00	0.00	0.00
5	Mining and Processing of Nonmetal Ores	1.12	0.00	−1.12	−100.00
6	Manufacture of Foods and Tobacco	230.61	398.71	168.11	72.90
7	Manufacture of Textile	25.65	10.92	−14.73	−57.43
8	Manufacture of Wearing Apparel, Leather, Feather and Related Products	80.39	168.42	88.03	109.49
9	Processing of Timber, Manufacture of Furniture	23.57	19.10	−4.47	−18.96
10	Manufacture of Paper, Printing and Articles For Culture, Education and Sport Activity	20.94	21.43	0.49	2.32
11	Processing of Petroleum, Coking, Processing of Nuclear Fuel	8.40	60.02	51.61	614.12
12	Manufacture of Chemical Materials	142.36	147.82	5.46	3.84
13	Manufacture of Non-metallic Mineral Products	75.87	14.30	−61.57	−81.15
14	Smelting and Pressing of Metals	3.57	0.00	−3.57	−100.00
15	Manufacture of Metal Products	28.93	22.53	−6.41	−22.14
16	Manufacture of General and Special Purpose Machinery	3.87	3.30	−0.57	−14.61
17	Manufacture of Transport Equipment	52.95	143.65	90.70	171.30
18	Manufacture of Electrical Machinery and Equipment	99.58	124.66	25.08	25.18
19	Manufacture of Communication Equipment, Computers and Other Electronic Equipment	44.96	65.43	20.46	45.52
20	Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work	3.32	8.85	5.52	166.22
21	Manufacture of Artwork and Other Manufacturing (Including Recycling and Disposal of Waste)	15.68	44.36	28.68	182.94
22	Production and Distribution of Electric Power and Heat Power	149.74	384.45	234.71	156.75
23	Production and Distribution of Gas	21.46	25.24	3.78	17.61
24	Production and Distribution of Water	10.42	37.64	27.23	261.38
25	Construction	0.00	39.76	39.76	0.00
26	Transport, Storage and Post	85.15	210.83	125.68	147.61
27	Wholesale, Retail Trade and Hotel,Restaurants	93.86	176.09	82.23	87.61
28	Others	202.80	583.08	380.29	187.52

[a] This table generates from our estimate.

Appendix D. Household consumption

Table D
Household consumption of China in 2000 and 2010.[a]

No.	Sector	Household consumption in 2000 (billion Yuan)	Household consumption in 2010 (billion Yuan, after adjustment)
1	Farming, Forestry, Animal Husbandry, Fishery and Water Conservancy	1095.55	977.17
2	Mining and Washing of Coal	8.03	10.97
3	Extraction of Petroleum and Natural Gas	1.70	0.00
4	Mining and Processing of Metal Ores	0.00	0.00
5	Mining and Processing of Nonmetal Ores	2.38	0.00
6	Manufacture of Foods and Tobacco	882.79	2238.59
7	Manufacture of Textile	73.77	41.17
8	Manufacture of Wearing Apparel, Leather, Feather and Related Products	267.22	665.16
9	Processing of Timber, Manufacture of Furniture	51.80	58.98
10	Manufacture of Paper, Printing and Articles For Culture, Education and Sport Activity	41.79	61.65
11	Processing of Petroleum, Coking, Processing of Nuclear Fuel	12.34	110.26
12	Manufacture of Chemical Materials	168.97	268.63
13	Manufacture of Non-metallic Mineral Products	72.15	24.85
14	Smelting and Pressing of Metals	2.55	0.00
15	Manufacture of Metal Products	34.96	39.06
16	Manufacture of General and Special Purpose Machinery	5.75	7.30
17	Manufacture of Transport Equipment	92.05	376.71
18	Manufacture of Electrical Machinery and Equipment	138.22	260.30
19	Manufacture of Communication Equipment, Computers and Other Electronic Equipment	109.01	201.32

(continued on next page)

Table D (*continued*)

No.	Sector	Household consumption in 2000 (billion Yuan)	Household consumption in 2010 (billion Yuan, after adjustment)
20	Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work	6.50	26.51
21	Manufacture of Artwork and Other Manufacturing (Including Recycling and Disposal of Waste)	40.22	192.38
22	Production and Distribution of Electric Power and Heat Power	70.50	222.35
23	Production and Distribution of Gas	21.08	78.85
24	Production and Distribution of Water	14.83	72.62
25	Construction	0.00	100.23
26	Transport, Storage and Post	165.27	608.80
27	Wholesale, Retail Trade and Hotel,Restaurants	347.31	1322.63
28	Others	710.42	3652.85

[a] Household consumption in 2000 is from input–output table in 2000 and that in 2010 generates from our estimate.

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