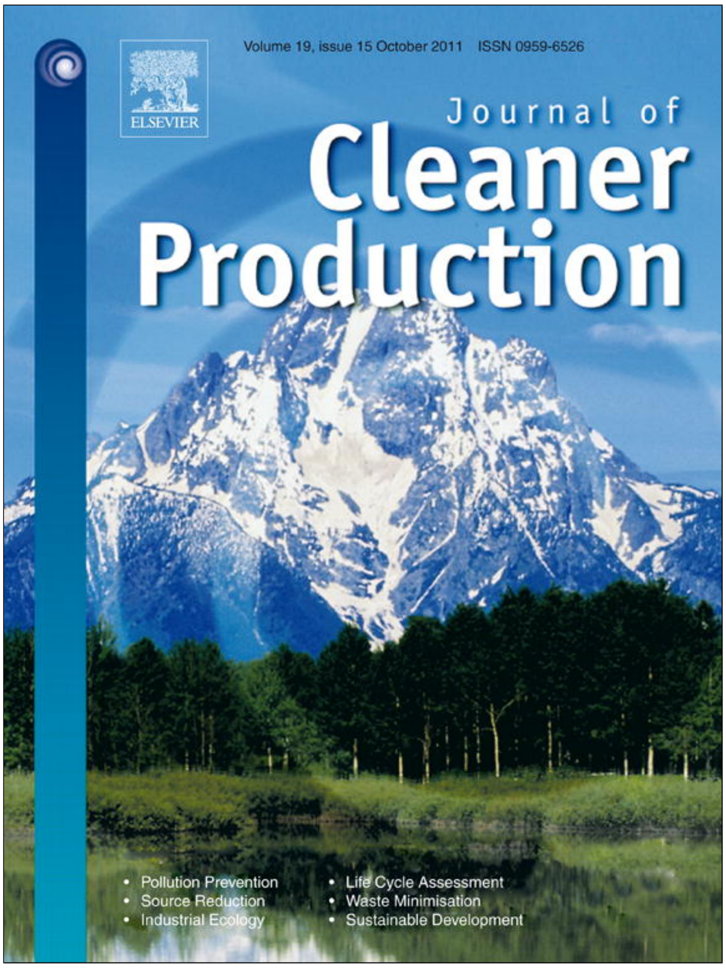
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China's carbon emissions from urban and rural households during 1992–2007

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ABSTRACT

In China, Rapid economic growth has stimulated fast urban expansion and rural household income and consumption expenditure. In current paper, an input–output method is used to determine the impact of China's increased urban and rural household consumption on carbon emissions. The results shows that the direct and indirect CO_2 emission from household consumption accounted for more than 40% of total carbon emissions from primary energy utilization in China in 1992–2007. The population increase, expansion of urbanization and the increase of household consumption per capita all contribute to an increase of indirect carbon emissions, while carbon intensity decline mitigates the growth of carbon emissions. Therefore, at the domestic level, household consumption is of great significance for CO_2 emission, which could be mitigated through changing the composition of goods and services consumed by households, and switching to consumption pattern of less carbon-intensive products. The government must consider the substantial contribution of household consumption to carbon emissions when China is encouraging consumption in order to address the current global financial crisis.

1. Introduction

At the 15th Economic Leaders' Meeting of the Asia-Pacific Economic Cooperation (APEC) forum in 2007, Chinese President Hu Jintao said that China should ensure that both production and consumption are compatible with sustainable development, develop low-carbon economy, build a resources-saving and environment-friendly society and thus address the root cause of climate change. One of the most important contents for both sustainable development and low-carbon economy is to induce household consumption. Household consumption generates a demand for goods and services, including energy products. Production of goods and services, meanwhile, requires the direct use of inputs from various sectors including energy sectors, which in turn use inputs from other sectors (indirect use) in the different stages of the industrial process. Therefore, household consumption has an important impact on energy use and the related environmental problems.

IPCC (2001) suggests change in consumption patterns as a possible approach to alleviate the effects of climate change. Most OECD countries have implemented policies to reduce the environmental impacts from household activities: some of these aims to influence household decision making directly by encouraging energy conservation or waste recycling, for example; others influence the options open to consumers in the market by imposing standards, or by using taxes or fees to increase the relative prices of products with greater negative environmental impacts (Geyer-Allély and Zacarias-Farah, 2003).

Since Deng Xiaoping's famous tour of southern China in 1992, amazing changes take place in China. China's household income and consumption has expanded rapidly with the rapid economic growth. The average household consumption per capita increased by 2.19-fold, 1.61-fold for urban household and 1.32-fold for rural household in 1992–2007. The most direct and significant result of China's economic growth is the amazing improvement in people's life quality, they are no longer satisfied with enough provision of food and clothing, but are also eager to obtain a quality life characterized with high quality food, comfortable living, health care and gradually adopting western lifestyles (Hubacek et al.,

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Table 1
Overview of studies about the energy requirement and carbon emissions of household consumption.

Description	Conclusions
Vringer and Blok (1995): The direct and indirect energy requirements of households in the Netherlands, based on the data of 350 consumption categories	54% of energy demand of household was direct. Attention needs to be given not only to the direct energy consumption (including the category 'petrol') but also to the consumption categories 'transport', 'education' and 'leisure'.
Munksgaard et al. (2000): Impact of household consumption on CO_2 emissions, based on the input–output table of 117 sectors	Growth in Danish household consumption is the key to understanding the increase in CO_2 emissions.
Wier et al. (2001): Effects of household consumption patterns on CO_2 requirements, based on the input–output table of 130 sectors	Energy and CO_2 requirements are positively correlated with household expenditure, and different family types have different CO_2 requirements.
Pachauri and Spreng (2002): Direct and indirect energy requirements of households in India, based on the data of 350 consumption categories and the input–output table of 115 sectors	Total household energy consumption comprises 75% of the total energy consumption in India, and the main drivers of this increase have been: the growing expenditure per capita, population and increasing energy intensity.
Reinders et al. (2003): The direct and indirect energy requirement of households in the European Union	Difference between countries in the total energy requirement of household are mainly due to difference in total household expenditure, and the indirect energy requirement is linearly related to the total household expenditure in 11 EU member states.
Pachauri (2004): An analysis of cross-sectional variations in total household energy, using household survey data	Total household expenditure or income level is the most important explanatory variable.
Bin and Dowlatabadi (2005): Consumer lifestyle approach to US energy use and the related CO_2 emissions, divided into 10 consumption categories	More than 80% of the energy used and the CO_2 emitted are caused by consumer demands and the economic activities to support these demands. Characterization of both direct and indirect energy use and emissions is critical to the design of more effective energy and CO_2 emission policies.
Cohen et al. (2005): Energy requirements of households in Brazil, divided into 12 consumption categories	The total energy intensity of household expenditure increases with income level.
Park and Heo (2007): The direct and indirect household energy requirements in the Republic of Korea from 1980 to 2000 – An input–output analysis, based on the input–output table of 168 sectors	Korean household sector was responsible for about 52% of the national primary energy requirement, and more than 60% was indirect, so not only direct but also indirect household energy requirement should be the target of energy conservation policies.
Nansai et al. (2007): Proposal of a simple indicator for sustainable consumption: classifying commodities into three types focusing on their optimal consumption levels based on the input–output table of 94 sectors	A compact indicator was proposed to identify the environmental characteristics of commodities.
Sánchez-Chóliz et al. (2007): Environmental impact of household activity in Spain based on SAM model	Pollution in Spain is closely linked to food production, energy, extractive industries and paper manufacturing.
Nansai et al. (2008): Identifying common features among household consumption patterns optimized to minimize specific environmental burdens based on the input–output table of 399 sectors	There is an optimal household consumption pattern to minimize environmental burden.
Feng and Zou (2011): The impact of household consumption on energy use and CO_2 emissions in China based on consumer lifestyle approach	Direct energy consumption is diverse for urban households and simple for rural households in China. Indirect energy consumption and CO_2 emissions for urban households are much greater than the direct consumption values.

2009). Accordingly the composition of consumption has changed greatly; Engel's coefficient[1] decreased by 17.2% (from 53.0% to 35.8%) for urban households and by 14.6% (from 57.6% to 43.0%) for rural households, which means that the share of food consumption in the total expenditure decreased greatly. Moreover, an upgrade of consumption structure is taking place; private cars, air-conditioners, refrigerators and computers are becoming common appliances to common household, indicating that electric power and transport services will emerge to dominate energy use. In China, coal power plants were always responsible for more than 80% of total electricity generation, and carbon emission per kWh from electricity generation was obviously higher than the global average level (Wei et al., 2008), so the use of these appliances will also cause the more carbon emissions. In addition, income inequality between rural and urban areas became more and more pronounced, which means that their different impact on energy use and the related carbon emissions. So the role of household consumption should be considered seriously during building a resources-saving and environment-friendly society and developing low-carbon economy.

Integrating the upgrade of urban and rural household consumption structure with the increase of household consumption, this paper analyzes the carbon emissions of household consumption from 1992 to 2007. The current paper was different from some studies: (1) we improved the input–output model by considering the intermediate input of imported goods, which was different from the study for China by Wei et al. (2008); (2) we study the carbon emissions of rural and urban household consumption, and household at different income level, which was different from many studies for other countries; (3) we identify the impact of main driving factors on carbon emissions, which was different from the studies by Wei et al. (2008) and Feng et al. (2011). The present study will be helpful for China to guide the behavior of household consumption toward the development of a low-carbon economy because China is entering a rapid transition period to become a middle-income country.

2. The theoretical framework of the carbon emissions of household consumption

Household sector is an important consumption sector because more than 70% of final consumptions expenditure (Government consumption can only accounts for less than 30%) are conducted in household. Therefore, there have been many studies focused on them (Vringer and Blok, 1995; Munksgaard et al., 2000; Wier et al., 2001; Pachauri and Spreng, 2002; Reinders et al., 2003; Pachauri, 2004; Bin and Dowlatabadi, 2005; Cohen et al., 2005; Park and Heo, 2007; Nansai et al., 2007, 2008; Sánchez-Chóliz et al., 2007; Feng and Zou, 2011), which were shown in Table 1. These studies

[1] Engel's coefficient refers to the percentage of expenditure on food in the total consumption expenditure, using the following formula:

$$\text{Engel's coefficient} = \frac{\text{Expenditure on food}}{\text{Total consumption expenditure}} \times 100\%$$

tried to give insight into the possibilities of reducing or limiting the energy requirement and environmental impact on society through changing consumption patterns.

Based on these studies, the energy requirement of household consumption is divided into the direct and indirect energy requirements. The direct energy requirements of households contain the energy use of households. The indirect energy requirements of households consist of the energy required for the production of goods and services and the energy needed by the energy supply system for production of this energy from primary energy, which could be found in Fig. 1. Then carbon emissions related to energy requirement also is divided into direct and indirect emissions.

It is showed from the calculation results of the household energy requirements and related carbon emissions that a major part of the energy requirement and related carbon emissions in the economy of a country is allocated to the household sector (52% for the Republic of Korea (Park and Heo, 2007); more than 80% for U.S. (Bin and Dowlatabadi, 2005); 75% for India (Pachauri and Spreng, 2002)). The studies demonstrate that the indirect energy requirement and related carbon emissions of households is becoming more and more important and that income growth is mainly determining this phenomenon, and they consider that it is important to shift consumption patterns. Zacarias-Farah and Geyer-Allély (2003) considered that shifting consumption patterns will require more emphasis on external driving factors and action by government and the private sector. Desmedt et al. (2009) considered that the tool designed to help make householders aware of their energy-related behavior and to provide recommendations on energy saving measures is effective, and there exists a large potential to reduce the demand by influencing behavior.

3. Methodology and data source

Now input–output methods are usually used to calculate the energy requirement and the related carbon emissions of household consumption. Kok et al. (2006) discern and describe the three methods: i) The basic input–output method; ii) the input–output consumption expenditure method; iii) the input–output process analysis. According to Kok et al. (2006), the input–output process analysis requires detailed life cycle data of all goods, all these data collection is time-consuming and it's difficult to get these data and ensure data quality, and it is the most accurate method but it is time-consuming, which is more suitable for micro-level analysis instead of energy and environmental analysis on the macro-level; the basic input–output method and the input–output consumption expenditure method can be used for analysis from a macro point of view.

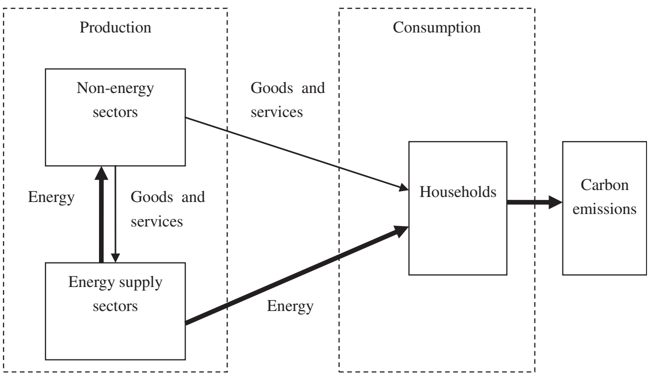

Fig. 1. Direct and indirect energy requirements on household consumption (based on Wilting et al., 1998).

This study is focused on total CO_2 emissions associated with Chinese rural and urban household consumption, with distinction between direct and indirect emissions. Direct emissions are those associated with the consumption of energy commodities in a household, i.e. electricity, heating, gas and other liquids. Indirect emissions are those associated with the production of all other commodities for households, i.e. emissions from the manufacture of furniture, food, clothes, services etc.

Total CO_2 emission from household consumption is calculated as:

$$C = C^d + C^p \tag{1}$$

Where:

C refers total CO_2 emissions from household consumption;

C^d refers the direct CO_2 emission from household consumption, and;

C^p refers the indirect CO_2 emission from household consumption.

3.1. Direct CO_2 emission

Direct CO_2 emission by urban/rural household is related to direct household energy requirement, energy mix and CO_2 emissions factors:

$$C_i^d = \sum_k f_k E_k \tag{2}$$

Where:

i refers the urban and rural household;

k refers is the type of energy use, and;

f_k refers CO_2 emission factor of k energy use.

In order to quantify the contribution of different factors to total change in emissions, we use the Sato-Vartia index method:

$$C^d = \sum_{i=1}^{2} C_i^d = \sum_{i=1}^{2} P \times \frac{P_i}{P} \times \frac{E_i}{P_i} \times \frac{C_i}{E_i} = \sum_{i=1}^{2} P \times S_i \times e_i \times M_i \tag{3}$$

Where: P is population; P_i is the urban/rural household population; E_i is the direct energy requirement of the urban/rural household; S_i is the share of the urban/rural household population; e_i is the direct energy requirement per capita of the urban/rural household; and M_i is the direct energy mix of the urban/rural household.

The effect of different factors can be calculated as following:

$$\text{Population effect} = \sum_{i=1}^{2} L\left(C_{i,t}^d, C_{i,t-1}^d\right) \cdot \ln\left(\frac{P_t}{P_{t-1}}\right) \tag{4}$$

$$\text{Urbanization effect} = \sum_{i=1}^{2} L\left(C_{i,t}^d, C_{i,t-1}^d\right) \cdot \ln\left(\frac{S_{i,t}}{S_{i,t-1}}\right) \tag{5}$$

Energy use per capita effect of urban/rural household

$$i = L\left(C_{i,t}^d, C_{i,t-1}^d\right) \cdot \ln\left(\frac{e_{i,t}}{e_{i,t-1}}\right) \tag{6}$$

Energy mix effect of urban/rural household

$$i = L\left(C_{i,t}^d, C_{i,t-1}^d\right) \cdot \ln\left(\frac{M_{i,t}}{M_{i,t-1}}\right) \tag{7}$$

$$L(a,b) = \begin{cases} \dfrac{a-b}{\ln a - \ln b}, a \neq b \\ a, a = b \end{cases} \quad (8)$$

The method is described in detail elsewhere (Sato, 1976; Vartia, 1976).

3.2. Indirect CO_2 emission

Indirect CO_2 emission from household consumption is calculated with the input–output method. Because we study the macro impact of urban and rural household consumption and it is very difficult to get the life cycle data of all goods in China, we used the basic input–output method to calculate the indirect carbon emissions of household consumption and used input–output consumption expenditure method to calculate the indirect carbon emissions of households at different income level instead of input–output process method. The method used here closely parallels similar studies performed in other countries.

For Chinese input–output tables, the direct requirements matrix A does not distinguish between domestically produced and imported goods. Thus, it is common (where import flow matrices are unavailable) to derive new requirements matrices in which only domestic goods are included (Weber et al., 2008). This method assumes that the same share of imports is present in each sector's demand.

The indirect CO_2 emission from household consumption is:

$$C_i^p = \sum_k f_k e_k \left(I - A^d\right)^{-1} F_i \quad (9)$$

$$A^d = \left(I - \text{diag}\left(\frac{\text{IM}}{X + \text{IM} - \text{EX}}\right)\right) A \quad (10)$$

where: e_k is the direct energy intensity of production sectors, A^d is the domestic technical matrix, A is the technical matrix, IM is the import vector, EX is the export vector, X is the output vector, $(I–A^d)^{-1}$ is the Leontief inverse matrix, and F_i is the consumption of household i. The household final demand does not distinguish between domestic goods and services and imports; because we consider the impact of the total consumption needs, we assume that the energy intensity of imported goods is equal to that of domestic goods.

In order to quantify the contribution of different factors that affect the total change in emissions, we use the Logarithmic mean Divisia index method to decompose the effects of changes in population, urbanization, consumption per capita, consumption structure, and carbon intensity on indirect CO_2 emissions by household consumption, as follows:

$$C^p = \sum C_{ij}^p = \sum_{ij} P \times \frac{P_i}{P} \times \frac{Q_i}{P_i} \times \frac{Q_{ij}}{Q_i} \times \frac{C_{ij}}{Q_{ij}}$$
$$= \sum_{ij} P \times S_i \times q_i \times M_{ij} \times c_{ij} \quad (11)$$

$$\text{Population effect} = \sum_{ij} L\left(C_{ij,t}^p, C_{ij,t-1}^p\right) \cdot \ln\left(\frac{P_t}{P_{t-1}}\right) \quad (12)$$

$$\text{Urbanization effect} = \sum_{ij} L\left(C_{ij,t}^p, C_{ij,t-1}^p\right) \cdot \ln\left(\frac{S_{i,t}}{S_{i,t-1}}\right) \quad (13)$$

Effect of consumption per capita of household

$$\sum_{ij} L\left(C_{ij,t}^p, C_{ij,t-1}^p\right) \cdot \ln\left(\frac{q_{i,t}}{q_{i,t-1}}\right) \quad (14)$$

Effect of consumption composition of household

$$\sum_{ij} L\left(C_{ij,t}^p, C_{ij,t-1}^p\right) \cdot \ln\left(\frac{M_{ij,t}}{M_{ij,t-1}}\right) \quad (15)$$

Effect of carbon intensity of household

$$\sum_{ij} L\left(C_{ij,t}^p, C_{ij,t-1}^p\right) \cdot \ln\left(\frac{c_{ij,t}}{c_{ij,t-1}}\right) \quad (16)$$

where j is the different consumption groups, Q_i is the consumption by household i, Q_{ij} is the consumption expenditure of groups j by household i, $\frac{C_{ij}}{Q_{ij}} = c_{ij}$ is the carbon emissions per unit of consumption, which shows the change of carbon intensity, $\frac{Q_i}{P_i} = q_i$ is the consumption per capita by household i, and $\frac{Q_{ij}}{Q_i} = M_{ij}$is the consumption composition of household i.

3.3. Data source

All the analysis in this paper is based on the available data from China's input–output tables in 1992, 1997, 2002 and 2007, so we analyze carbon emissions from household during 1992–2007 in order to keep consistent data and discussion. China's input–output tables for the years 1992, 1997, 2002 and 2007 were all in current prices, and the energy sectors include coal mining, oil and gas mining, petroleum products, electricity, and town gas and heat supply. Some of these are primary energy sectors and others are energy conversion sectors. In order to avoid energy "double counting", the energy use of energy conversion sectors is set to zero.

Energy consumption data for 1992, 1997, 2002 and 2007 are taken from the China Energy Statistical Yearbook (State Statistical Bureau, 1998; 2010). In this paper, CO_2 emissions come from the use of primary fossil energy use. The expenditure data for rural and urban households at different income levels in 2007 are taken from the China Statistical Yearbook (State Statistical Bureau, 2008).

4. Results and discussion

4.1. Total CO_2 emissions from China's household consumption

In this study, total carbon emissions by urban and rural households are calculated in terms of total household consumption, including domestic and imported products (we estimate that about

Table 2
Total CO_2 emissions from household consumption in 1992–2007.

CO_2 emissions (MtC)	1992	1997	2002	2007
Total from households	355.55	383.59	440.92	701.56
Total from urban households	180.51	210.50	303.15	510.37
Direct emissions	53.94	54.00	62.72	116.13
Indirect emissions	126.57	156.50	240.43	394.24
Total from rural households	175.04	173.09	137.77	191.19
Direct emissions	47.40	42.42	46.40	77.17
Indirect emissions	127.64	130.67	91.37	114.02
The increase (%)	–	7.89	14.95	59.11
Household carbon emissions as proportion of national emissions (%)	49.21	47.83	47.25	42.17

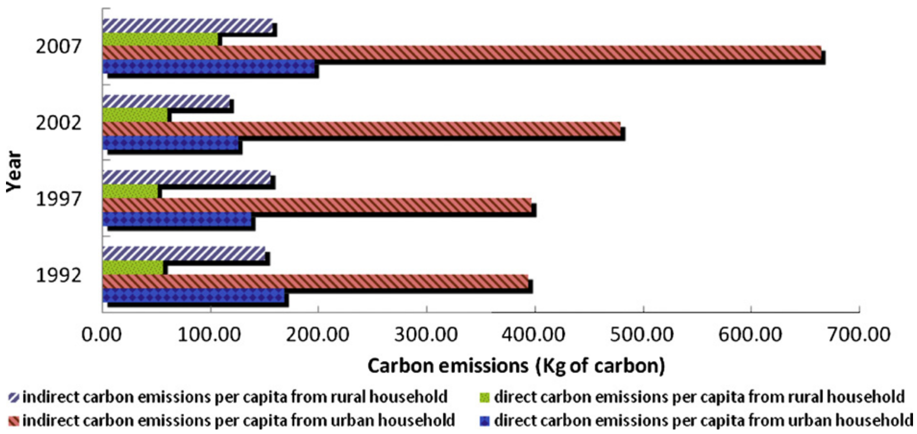

Fig. 2. CO_2 emissions per capita from household consumption.

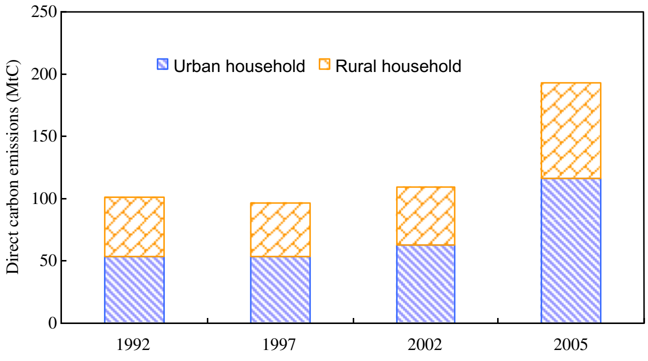

Fig. 3. Direct CO_2 emissions from urban and rural household consumption.

3% of imported products are included in the final demand of household consumption based on estimation for import statistics in 2007).

Table 2 shows the direct and indirect carbon emissions from rural and urban household consumption. The proportion of the national total CO_2 emissions was more than 40%, as shown in Table 2.

In 1992–1997, 1997–2002, and 2002–2007, total CO_2 emissions by household consumption increased by 7.89%, 14.95% and 59.11%, respectively. The large carbon emissions from households are closely related with the energy mix, which is dominated by coal, and the lower energy efficiency of domestic goods designed to meet the needs of household consumption. The total carbon emissions of both urban and rural households are increasing, but the proportion of national carbon emissions from primary fossil fuel is still lower than those of OECD countries.

Meanwhile, carbon emissions per capita from urban and rural household also present an upward trend, which can be found in Fig. 2. Due to the more urban household consumption expenditure in spite of the less urban population, direct and indirect carbon emissions per capita from urban household were obviously higher than those of rural household, especially in 2007. If the carbon emission per capita from rural household is equal to that from urban household in 2007, then total emission from rural household will be 625.29 MtC, and increase by 127.05% compared with the current level. Meantime, the consumption expenditure of urban household will expand further, so the carbon emissions will also increase. So how to induce rural and urban household consumption change is an important issue while China's government encourages household consumption increase to ensure the economic growth.

This result is lower than those of some studies (Bin and Dowlatabadi, 2005; Park and Heo, 2007; Pachauri and Spreng, 2002), the proportion is more than 80% for U.S. (Bin and Dowlatabadi, 2005), is 52% for the republic of Korea (Park and Heo, 2007), and is 75% for India (Pachauri and Spreng, 2002) because of the difference of energy types covered, household

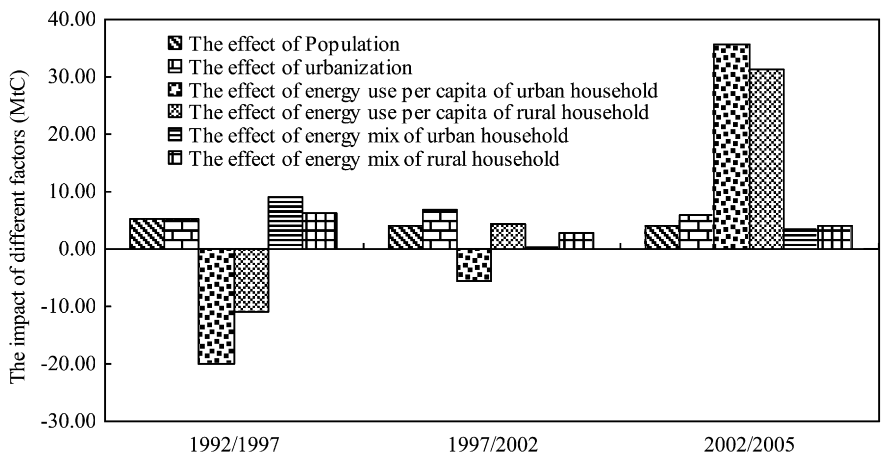

Fig. 4. The impact of different factors on direct carbon emissions.

consumption scale and composition, and methodology used. Also, this differs from those presented by Wei et al. (2007, 2008) for the following reasons. (1) We improved the input–output model by considering the intermediate input of imported goods. (2) Household consumption comes from input–output tables that do not include expenditure survey data. (3) The energy data for 2002 used in this study were corrected by State Statistical Bureau in 2010. (4) Carbon emissions are calculated in this study by the primary energy use other than the final end-use.

4.2. Direct CO_2 emissions from household consumption

Direct CO_2 emissions from household consumption in 1992, 1997, 2002 and 2007 are presented in Fig. 3. In 1992–2002, total direct CO_2 emissions were kept at a reasonably stable level of 110 MtC due to reduction of direct energy requirements. However, in 2007 total direct CO_2 emissions increased by 77.14%, with a similar increase from urban and rural households.

Direct carbon emissions from households come mainly from the use of coal and electricity. From 1992 to 2007, the use of coal in urban households decreased rapidly, while the demand for electricity grew increasingly and became the largest energy demand in 2007. However, the energy consumption in rural households was still dominated by the use of coal, most of which was used for cooking and for heating in winter.

Although the urban population is much less than the rural population, the direct carbon emissions are markedly higher than those of the rural households because non-commercial energy consumption still plays a dominant role in Chinese rural households. In 2007, the consumption of crop straw was 159.78 Mtce, which was far greater than the commercial energy use, and up to 2007, an estimated 28 thousand rural villages, about 7 million families or 30 million people, had no access to electricity (International Energy Network, 2008). The direct combustion of coal and crop straw indoors was a threat to the health of the members of rural households, especially for women and children.

A further decomposition analysis showed that population increase and urbanization drove the change of direct carbon emissions, which is illustrated by Fig. 4. From 1992 to 2002, the reduction of energy requirement per capita of urban and rural households reduces 25.61 MtC and 6.34 MtC respectively, but population increase, urbanization expansion and variation of energy mix increase 9.23 MtC, 12.14 MtC and 18.36 MtC respectively, so overall direct carbon emissions was lowered only 7.78 MtC, which means the reduction of energy requirement per capita offset the effect of population increase, urbanization and energy mix. From 2002 to 2007, all factors, except the energy mix of rural household, contributed to the increase of direct carbon emissions of households. These data suggest that direct carbon emissions from urban and rural households will increase with increasing population, energy use per capita, and expanding urbanization.

4.3. Indirect CO_2 emissions from China's household consumption

The amount of indirect carbon emissions from consumption by urban and rural households was greater than the direct carbon emissions. So, changes of consumption patterns are very important for developing a low-carbon society.

Fig. 5 shows the indirect carbon emissions from consumption by rural and urban households in 1992–2007. In 1992, the indirect carbon emissions of urban and rural households were 126.57 MtC and 127.64 MtC respectively. In 1997, 2002 and 2007, indirect carbon emissions from urban household consumption were markedly higher than those from rural households due to the rapid increase in the consumption expenditure of urban households. In 2002 and 2007, indirect carbon emissions of urban households were 1.63 and 2.46-fold greater than those of rural households.

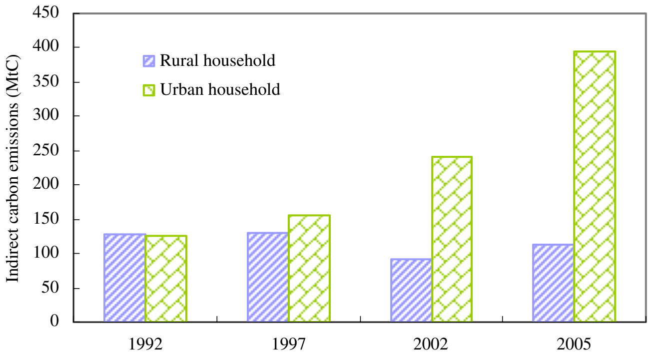

Fig. 5. The indirect carbon emissions from household consumption.

For urban households, the consumption for Miscellaneous commodities and service led to the most of carbon emissions (as shown in Table 3) because the consumption expenditure accounted for 42% of total urban household consumption; Residence and food and Tobacco also caused the more carbon emissions, but their driving forces were different: carbon emissions form Residence was driven by the higher carbon intensity (is 8 times as much as that of Food and tobacco, and Miscellaneous commodities and service); carbon emissions from Food and tobacco was driven by the higher consumption (it accounted for 29.54%, Residence only 3.63%). For rural household, the consumption for food and tobacco led to the most of carbon emissions (as shown in Table 3) because its consumption accounted for 39% of total rural household consumption. So, for rural and urban households, it is important to consider different policy (policies focused on guiding consumption behavior or decreasing carbon intensity) to mitigate carbon emissions.

Indirect carbon emissions depends on many factors, such as total consumption, household consumption behavior, consumption composition and carbon intensity, etc., so we analyzed the change of indirect carbon emissions on the basis of Eq. (11) in page 12.

From 1992 to 2007, various factors contributed to an increase of indirect carbon emissions, such as the population increase, expansion of urbanization, and the increase of household consumption per capita and the change of consumption composition, which impacts were respectively 36.72 MtC, 71.44 MtC, 332.32 MtC and 30.14 MtC as shown in Fig. 6, in another hand, variation of carbon intensity mitigated growth of carbon emissions from 1992 to 2007 which decreased 216.55 MtC.

Table 3
The indirect carbon emissions of household consumption categories in 2007.

	Consumption (billion yuan)		Carbon emissions (MtC)	
	Rural Household	Urban Household	Rural Household	Urban Household
Food and tobacco	1008.30	2133.81	31.18	71.90
Clothing, Household facilities and medicine	247.96	908.09	18.69	64.47
Residence	65.60	262.07	18.91	74.08
Transport and communication service	150.37	524.15	9.77	33.60
Education, cultral and recreation service	160.16	336.24	6.07	13.26
Miscellaneous commodities and service	799.34	3059.17	29.40	136.94
Total	2431.72	7223.54	114.02	394.24

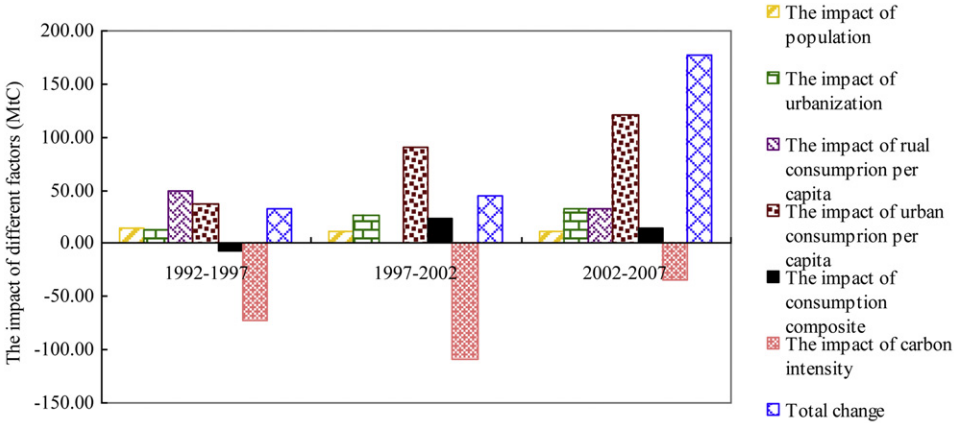

Fig. 6. The impact of different factors on indirect carbon emissions.

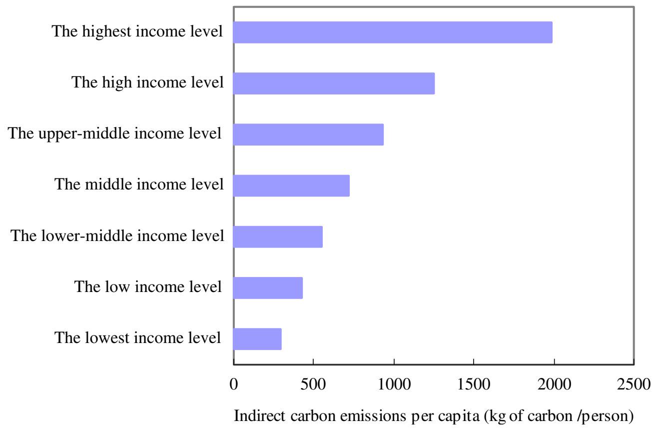

Fig. 7. The indirect carbon emissions per capita of urban household consumption in 2007.

These suggest that household consumption composition become carbon-intensive and had a negative impact on developing a low-carbon society. National government's plans to ensure economic growth must emphasize energy conservation and carbon emissions mitigation, and provide guidance for rational consumption behavior, and there must be an energy audit for producers. The security of Chinese energy supply and the commitment to reducing carbon intensity (carbon emissions per unit of gross domestic products decreased by 40–45% by 2020) will also be compromised.

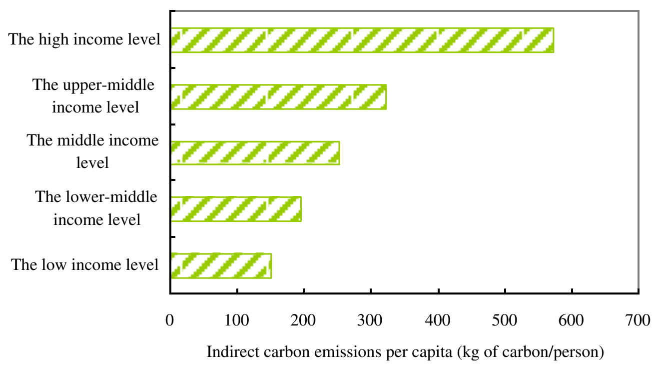

Fig. 8. The indirect carbon emissions per capita of rural household consumption in 2007.

4.4. CO_2 emission by urban and rural households at different income levels

With the rapid growth of economy in China, there is a marked income inequality between rural and urban households. In 2007, the income per capita in the highest income level of urban households was 25 times greater than that in the lowest income level of rural households, and this income gap affects indirect carbon emissions.

Fig. 7 and Fig. 8 show that there is a big difference in indirect CO_2 emission per capita at different income levels.[2] In urban households, indirect CO_2 emissions per capita reached 1987.81 kg of carbon for households with the highest income, were respectively 6.7 times higher than those of the lowest income household, and 4.7 times higher than those of the low income household, 3.6 times higher than those of the lower middle income household, 2.8 times higher than those of the middle income household, 2.1 times higher than those of the upper middle income household, and 1.6 times higher than those of the high income household.

For rural households, the values were 573.57 kg of carbon for high-income households, were respectively 3.8 times higher than those of the low income household, 2.9 times higher than those of the lower middle income household, 2.3 times higher than those of the middle income household, and 1.8 times higher than those of the upper middle income household.

The carbon emissions per capita are proportional to their expenditure level, which was shown in Fig. 9. The higher carbon

[2] Based on State Statistical Bureau(2008), all urban households in the sample are grouped, by per capita disposable income of the household, into groups of lowest income, low income, lower middle income, middle income, upper middle income, high income and highest income, each group consisting of 10%, 10%, 20%, 20%, 20%, 10% and 10% of all households respectively. For rural household, by per capita net income of the household, into groups of low income, lower middle income, middle income, upper middle income, and high income, each group consisting of 20% respectively. In 2007, for rural household, the average per capita net income of low income household was 1347 yuan; 2582 yuan for lower middle income household; 3659 yuan for middle income household; 5130 yuan for upper middle income household; 9791 yuan for high income household. For urban household, the average per disposable income of lowest income household was 4210 yuan; 6505 yuan for low income household; 8901 yuan for lower middle income household; 12042 yuan for middle income household; 16386 yuan for upper middle income household; 22234 yuan for high income household and 36785 yuan for highest income household.

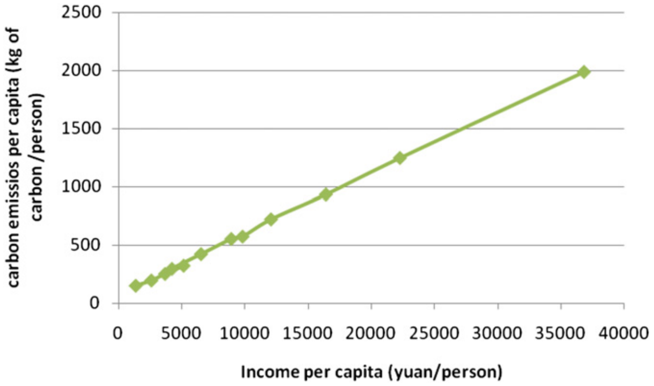

Fig. 9. The relationship between indirect carbon emissions per capita and income per capita in 2007.

emissions of household in the higher income level means that they need more goods and services to meet their demands due to their higher income. Their lifestyle will have great impact on the household in the other income level, so it is urgent to induce their rational consumption behaviors.

In the future, with increasing income of both urban and rural households, as well as increasing urbanization, the indirect CO_2 emissions from Chinese households will continue to increase. When encouraging consumption to ensure economic growth, government can give priority to guide responsible behavior of households, especially in higher income levels, and stimulate household consumption in the lower income level, especially in rural households, which may have a smaller impact on carbon emissions.

5. Conclusions and policy implications

Our study showed that the impacts of urban and rural households consumption on CO_2 emission was more than 40% of total carbon emissions from primary energy utilization in 1992–2007 in China. The consumption scaling-up of urban and rural households, the urban population growth, and the changing household consumption composition are main reasons for the increase of household carbon emissions. The population increase, expansion of urbanization, the increase of household consumption per capita and the change of consumption composition respectively increase 36.72 MtC, 71.44 MtC, 332.32 MtC and 30.14 MtC, but the decline of carbon intensity has also slowed the growth rate of carbon emissions which accordingly decrease 216.55 MtC. Therefore, it is necessary to guide household consumption to change toward less carbon-intensive products and services; on the other hand, the carbon intensity of products should be further lowered so as to reduce the growth rate of household CO_2 emissions.

China is facing a dilemma; it is necessary to encourage consumption to ensure domestic economic growth, and meanwhile it must mitigate the rapid increase of carbon emissions to respond to international pressure and a stated commitment to decreasing carbon intensity. Therefore, from the perspective of consumption driving economic growth, stimulation of consumption should also consider the environmental impact of household consumption. For Chinese government, it is urgent to give priority to guide responsible behavior of households, especially in higher income levels, and stimulate household consumption in the lower income level, especially in rural households, which may have a smaller impact on carbon emissions. Meanwhile, government should carry out some environmental policies such as labeling or a green levy programs in which the most CO_2-intensive commodities bear the highest levies, would encourage consumers to spend even more of their budget on low carbon-intensity goods and services.

In this paper, we used average prices to construct energy input–output tables, however urban and rural households paid higher prices for the same fuel than the industry in China, so industries would have used more energy which means higher ratio of indirect carbon emissions. Because we use the direct energy requirement from the statistics of State Statistical Bureau, so this kind of construction of energy input–output tables result in an underestimation of indirect household energy requirement. Further, more research should be done on indirect household carbon emissions from every household consumption item using a hybrid method in order to provide some detailed supports for the induction of household consumption behaviors. Based on above results, we could further analyze the optimal household consumption patterns optimized to minimize environmental burdens and the effective policy tools to shift consumption patterns.

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References

Bin, S., Dowlatabadi, H., 2005. Consumer lifestyle approach to US energy use and the related CO_2 emissions. Energy Policy 33 (2), 197–208.
Cohen, C., Lenzen, M., Schaeffer, R., 2005. Energy requirements of households in Brazil. Energy Policy 33, 555–562.
Desmedt, J., Guy Vekemans, G., Maes, D., 2009. Ensuring effectiveness of information to influence household behaviour. Journal of Clean Production 17 (4), 455–462.
Feng, Z.-H., Zou, L.-L., Wei, Y.-M., 2011. The impact of household consumption on energy use and CO_2 emissions in China. Energy 36, 656–670.
Geyer-Allély, E., Zacarias-Farah, A., 2003. Policies and instruments for promoting sustainable household consumption. Journal of Clean Production 11 (8), 923–926.
Hubacek, K., Guan, D., Barrett, J., Wiedmann, T., 2009. Environmental implications of urbanization and lifestyle change in China: Ecological and Water Footprints. Journal of Clean Production 17 (14), 1241–1248.
International Energy Network, 2008. Chinese Solar Industry Forecasting in 2008–2010. http://www.in-en.com/newenergy/html/newenergy-1439143966158060.html.
IPCC, 2001. Intergovernmental Panel on Climate Change (IPCC), Climate change 2001, Mitigation, Third Assessment Report, Intergovernmental Panel on Climate Change.
Kok, R., Benders, R.M.J., Moll, H.C., 2006. Measuring the environmental load of household consumption using some methods based on input–output energy analysis: a comparison of methods and a discussion of results. Energy Policy 34 (17), 2744–2761.
Munksgaard, J., Pedersen, K.A., Wier, M., 2000. Impact of household consumption on CO_2 emissions. Energy Economics 22, 423–440.
Nansai, K., Kagawa, S., Moriguchi, Y., 2007. Proposal of a simple indicator for sustainable consumption: classifying commodities into three types focusing on their optimal consumption levels. Journal of Clean Production 15 (10), 879–885.
Nansai, K., Inaba, R., Kagawa, S., Moriguchi, Y., 2008. Identifying common features among household consumption patterns optimized to minimize specific environmental burdens. Journal of Clean Production 16 (4), 538–548.
Pachauri, S., 2004. An analysis of cross-sectional variations in total household energy. Energy Policy 32, 1723–1735.
Pachauri, S., Spreng, D., 2002. Direct and indirect energy requirements of households in India. Energy Policy 30 (6), 511–523.

Park, H.-C., Heo, E., 2007. The direct and indirect household energy requirements in the Republic of Korea from 1980 to 2000 – An input–output analysis. Energy Policy 35 (5), 2839–2851.

Reinders, A.H.M.E., Vringer, K., Blok, K., 2003. The direct and indirect energy requirement of households in the European Union. Energy Policy 31 (2), 139–153.

Sato, K., 1976. The ideal log-change index number. Review of Economics and Statistics 58 (2), 223–228.

Sánchez-Chóliz, J., Duarte, R., Mainar, A., 2007. Environmental impact of household activity in Spain. Ecological Economics 62 (2), 308–318.

State Statistical Bureau, 1998. China Energy Statistical Yearbook 1991-1996. China Statistical Press, Beijing.

State Statistical Bureau, 2008. China Statistical Yearbook. China Statistical Press, Beijing.

State Statistical Bureau, 2010. China Energy Statistical Yearbook 2009. China Statistical Press, Beijing.

Vartia, Y.O., 1976. Ideal log-change index numbers. Scandinavian Journal of Statistics 3 (3), 121–126.

Vringer, K., Blok, K., 1995. The direct and indirect energy requirements of households in the Netherlands. Energy Policy 23 (10), 893–910.

Weber, C.L., Peters, G.P., Guan, D., Hubacek, K., 2008. The contribution of Chinese exports to climate change. Energy Policy 36 (9), 3572–3577.

Wei, Y.-M., Liu, L.-C., Liu, Fan Y., Wu, G., 2007. The impact of lifestyle on energy use and CO_2 emission: an empirical analysis of China's residents. Energy Policy 35 (1), 247–257.

Wei, Y.-M., Liu, L.-C., Liu, Fan Y., Wu, G., 2008. China Energy Report (2008): CO_2 Emission Research. Science Press, China. In Chinese.

Wier, M., Lenzen, M., Munksgaard, J., Smed, S., 2001. Effects of household consumption patterns on CO_2 requirements. Economic Systems Research 13 (3), 259–274.

Wilting, H.C., Biesiot, W., Moll, H.C., 1998. An Input–Output Based Methodology for the Evaluation of Technological and Demand-Side Energy Conservation Options. http://www.iioa.org/pdf/12th%20conf/wilting.pdf.

Zacarias-Farah, A., Geyer-Allély, E., 2003. Household consumption patterns in OECD countries: trends and figures. Journal of Clean Production 11 (8), 819–827.