Study on Direct and Indirect Household Energy Consumption and CO₂ Emissions in China

Jun DU, Hiroaki SHIRAKAWA, Ji HAN and Hidefumi IMURA

Abstract: Based on ninety-five-sector input-output tables for China for 1992, 1997 and 2002, this paper calculates the direct and indirect household energy consumption and associated CO₂ emissions and analyzes the impacts of different household lifestyles on China's energy use and CO₂ emissions during the period 1992–2002. Results reveal that more than 55% of household energy use and 58% of associated CO₂ emissions were indirect during the period. Annual energy use sustaining urban residents' lifestyle increased to 24GJ per capita and associated CO₂ emissions reached 2.4t per capita and it was 19.7GJ to sustain rural residents' lifestyle and associated CO₂ emissions was 1.8t per capita in 2002. Though the intensity of household energy use and associated CO₂ emissions declined, the total accounts had been rising slightly due to the increasing household consumption activity, number of households and change of expenditure structure, which surpassed the improvement of energy efficiency.

Key Words: household, energy consumption, CO₂ emissions, lifestyle, I-O analysis

INTRODUCTION

Energy use and associated CO₂ emissions are not only influenced by technology but also by human lifestyles and socio-cultural factors (Weber and Perrels, 2000). Knowing how lifestyle change contributes to the growing energy consumption and associated green house gas emissions is critical for the policy-makers for the conservation of environment and energy in China. From 1990 to 2004, China’s total energy consumption grew at 5.0% per annum from 18EJ (10¹⁸ J) to 58EJ (Sinton, 2004), and CO₂ emissions grew at 4.8% per year from 1,446 million tons(Mt) to 4,707 Mt (China). China was the second largest contributor to global CO₂ emissions, emitting 17% of global CO₂ in 2004. The household sector plays an important role in energy consumption and CO₂ emission in China. For example, in 2002, it contributed to 35% of China’s national energy use and accounted for 58% of national CO₂ emissions. To reduce energy consumption and CO₂ emissions, Chinese Government has promulgated a series of energy-environment policies and set a national mandatory target for energy intensity (20% reduction in 2010 based on the level of 2005)². However the research and efforts made in the policy area to pay attention to household sector and address consumer behavior towards sustainable consumption are yet limited in China.

This study aims to calculate direct and indirect household energy consumption and associated CO₂ emissions in China from 1992 to 2002 by using an input-output model. Furthermore we analyze the impacts of different lifestyles of urban and rural residents and households with different income levels on energy use and associated emissions, here lifestyle is a way of living and it is reflected by resident’s consumption behavior (Bör and Dowlatabadi, 2005).
Finally we discuss the responsible factors behind growing household energy use and CO₂ emission.

1. METHODS AND DATA

Energy consumed by households includes direct and indirect use. Direct use refers to the consumption of energy carriers purchased by the household itself. Indirect use refers to the energy embodied in the commodities and services which are finally consumed by the households. Methods that are widely applied to calculate both direct and indirect household energy consumption include three types: (i) input-output model based on national account e.g. Pachauri and Spreng (2002); (ii) input-output model combined with household expenditure data e.g. Bin and Dowlatabadi (2005); and (iii) hybrid input-output model combined with process analysis e.g. Vringer and Blok (1995). More detailed discussion on the strengths and limitations of the three types of methods see Kok et al. (2006). This work adopts the first method to calculate household energy consumption in china from 1992 to 2002 according to the data availability.


1. 1 Direct and indirect energy use

Energy directly consumed by the household includes electricity, natural gas, motor fuels and biofuels for rural residents. Indirect energy use includes energy used in the production, distribution and disposal of all goods and services consumed by the household (Kok et al, 2006) the amount and associated CO₂ emissions can be calculated according to the following equations:

\[ E_{\text{indirect}} = EI \times (I - A)^{-1} y \]  
\[ C_{\text{indirect}} = CI \times (I - A)^{-1} y \]

where \( E_{\text{indirect}} \) and \( C_{\text{indirect}} \) are indirect household energy consumption and associated CO₂ emissions; \( y \) is a vector of final demands of rural and urban households for each sector; \((I \cdot A)^{-1}\) is the Leontief inverse matrix; EI and CI are diagonal matrices indicating energy and CO₂ intensities, respectively, with each row representing the energy consumption and CO₂ emissions per unit output from each sector.

In this study, we use the input-output tables for 1992, 1997, and 2002 compiled from China National Bureau of Statistics. Data is recalculated from 118 (in 1992), 124 (in 1997) and 122 (in 2002) sectors to a consistent industry classification for 95 sectors.

1. 2 Energy intensity of household consumption

Energy intensity of household consumption is defined as household energy consumption (both direct and indirect) divided by associated household expenditure. To analyze the impact of lifestyles, we integrate 95 industrial sectors into eight consumption categories to represent residents' consumption behaviors: (i) Food, (ii) Clothing, (iii) Household facilities and services, (iv) Medicine and medical services, (v) Transport and communication, (vi) Education and recreation (vii) Residence, and (viii) Others. We calculated the energy intensity of household expenditure for each category and compared energy consumption and associated CO₂ emissions for different household groups based on the income level. Data on the expenditure of urban and rural households is available from China Urban Life and Price Yearbook and China Yearbook of Rural Household Survey (1993, 1998 and 2003). The expenditure for 1992 and 1997 in current price was converted to the constant price of 2002.

2. RESULTS

2. 1 Total household energy consumption and associated CO₂ emissions

Table 1 indicates that total household energy consumption grew slowly during the period 1992-2002. And the associated CO₂ emissions reached 2,484Mt in 2002. Direct household energy use is about 45%, 41%, and 45% of the total household energy use and direct CO₂ emissions from household is 42%, 33% and 36% of total emissions in 1992, 1997 and 2002. One of the reasons is the Asian economic crisis in 1997 and domestic reform policies reduced the consumption of residential indirect energy commodities, another
reason is that more and more households tend to use such clean direct energy as natural gas, electricity and LPG to replace relatively unclear fuel like coal. However, biofuels, including biogas, stalks and firewood, are still the major energy resources for rural household because of their cheap prices. The Chinese Government has made efforts to promote the utilization of biogas stove to replace firewood stove in the rural area, which continues to have 4.5% increase per year in biofuels consumption from 1997 to 2002.

Being the changes in consumption structure, household indirect energy use caused by household facilities grew fastest while household indirect energy use caused by clothing declined fastest in the period. But food as the most basic consumption is still the most energy-and CO₂-intensive consumption behavior among all consumption categories.

2. 2 Urban and rural household energy use and associated CO₂ emissions per capita

There is a certain gap in energy consumption between rural and urban inhabitants in China though rapid urbanization has contributed to gradual convergence of lifestyles between rural and urban residents. To analyze the household energy use and associated CO₂ emissions for urban and rural residents, we allocate two energy types — gasoline and diesel oil in direct energy use and their CO₂ emissions between urban and rural residents on transportation and communication category and the other energy types include raw coal, other washed coal, briquettes, coke oven gas, kerosene, LPG, natural gas, heat and electricity and their CO₂ emissions between urban and rural residents on residence category according the explanatory notes on statistical indicators by National bureau of statistics of China. Then we obtained total household energy use and associated CO₂ emissions per capita.

<table>
<thead>
<tr>
<th></th>
<th>1992</th>
<th>1997</th>
<th>2002</th>
<th>annual growth rates in percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household number(104 household)</td>
<td>30039</td>
<td>32663</td>
<td>35717</td>
<td>1.7</td>
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<tr>
<td>Household size(person)</td>
<td>3.95</td>
<td>3.69</td>
<td>3.51</td>
<td>-1.4</td>
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<tr>
<td>Direct energy use (PJ)</td>
<td>10509</td>
<td>10457</td>
<td>11903</td>
<td>-0.1</td>
</tr>
<tr>
<td>Coal and its products</td>
<td>3118</td>
<td>2640</td>
<td>1690</td>
<td>-3.5</td>
</tr>
<tr>
<td>Petroleum and its products</td>
<td>173</td>
<td>457</td>
<td>720</td>
<td>21.5</td>
</tr>
<tr>
<td>Natural gas</td>
<td>85</td>
<td>85</td>
<td>204</td>
<td>0.1</td>
</tr>
<tr>
<td>Heat and electricity</td>
<td>364</td>
<td>652</td>
<td>1045</td>
<td>12.4</td>
</tr>
<tr>
<td>Biogas, stalks and firewood</td>
<td>6728</td>
<td>6021</td>
<td>8245</td>
<td>-0.3</td>
</tr>
<tr>
<td>Direct CO₂ emission(Mt)</td>
<td>884</td>
<td>804</td>
<td>887</td>
<td>0.7</td>
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<tr>
<td>Indirect energy use(PJ)</td>
<td>12846</td>
<td>15214</td>
<td>14452</td>
<td>3.4</td>
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<tr>
<td>Food</td>
<td>4610</td>
<td>7225</td>
<td>4574</td>
<td>9.4</td>
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<td>Clothing</td>
<td>708</td>
<td>561</td>
<td>328</td>
<td>-6.4</td>
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<td>Household facilities</td>
<td>681</td>
<td>880</td>
<td>3937</td>
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<tr>
<td>Medicine and Medical Service</td>
<td>134</td>
<td>140</td>
<td>195</td>
<td>0.7</td>
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<td>Transport and communication</td>
<td>387</td>
<td>501</td>
<td>1133</td>
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<tr>
<td>Education and recreation</td>
<td>221</td>
<td>209</td>
<td>416</td>
<td>-1.1</td>
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<td>Residence</td>
<td>778</td>
<td>1454</td>
<td>2387</td>
<td>13.3</td>
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<tr>
<td>Others</td>
<td>5327</td>
<td>4245</td>
<td>1246</td>
<td>-4.4</td>
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<td>Indirect CO₂ emission(Mt)</td>
<td>1175</td>
<td>1629</td>
<td>1586</td>
<td>6.8</td>
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<td>Total direct and indirect(PJ)</td>
<td>23355</td>
<td>25670</td>
<td>26356</td>
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<tr>
<td>Total CO₂ emission(Mt)</td>
<td>2009</td>
<td>2434</td>
<td>2484</td>
<td>3.9</td>
</tr>
</tbody>
</table>

Note: 1) Share of household energy use in China's national energy use

2) Share of CO₂ emissions associated with household energy use in China's national CO₂ emission
use and associated CO₂ emissions of each consumption categories for urban and rural residents.

Fig.1 and Fig. 2 show that urban households consumed more energy and emitted more CO₂ per capita than rural households. In the period 1992–2002, on the one hand, energy used by urban residents for residence, education and recreation, medicine and medical services, household facilities and transportation and communication services had been increasing. However energy used for food, clothing and the others had been decreasing. On the other hand, energy used by rural residents for residence, household facilities and transportation and communication services had been growing. However energy used for food, clothing, education and recreation, medicine and medical services and others had been declining. Associated CO₂ emissions had similar trend.

Energy use sustaining urban residents' lifestyle was almost unchanged about 24GJ per capita and associated CO₂ emissions increased slightly from 2.1t to 2.4t per capita in the period. The largest energy-intensive consumption behavior of urban residents was residence, accounting for about 30% of the total household energy consumption. The most significant change of energy-intensive consumption behavior is household facilities, contributing to 4%-20% of the total household energy consumption from 1992 to 2002. Energy used and associated CO₂ emissions of per capita in rural areas changed slightly from 18GJ to 19.7GJ and 1.6t to 1.8t in 1992-2002.

The most energy-intensive rural household consumptions was residence, account for from 57% to 72% and the most change is also household facilities in the period 1992–2002. Comparing the lifestyles between urban and rural residents, we found urban households consumed more energy for education and recreation, medicine and medical services and transportation and communication than their rural counterparts.

2. 3 Intensities of energy and CO₂ emissions of household consumption

The intensities of energy and CO₂ emissions for both urban and rural household consumption declined because of the improvement of energy efficiency in the period 1992-2002. The intensities of energy and CO₂ emissions for urban household consumption were less than those of rural household consumption (Fig.3). However, total energy consumption and associated CO₂ emissions for urban households were more than that for rural households attributable to faster increase in urban household expenditure and income than rural households.

As shown in Fig.4 the energy consumed and CO₂ emitted by a person in urban areas with annual disposable income above 12000 Yuan (RMB) were 3.5-times and 3.6-times, respectively, of those of a person with annual disposable income below 4000 Yuan. As for the rural areas, the differences between a person with annual net income above 4000 Yuan and below 1000 Yuan are 4.8-times and 5.2-times. Generally speaking, an average person from high-income households consumed more energy and emitted more CO₂ than an average person from low-income households for both urban and rural residents.

2. 4 Changes in household energy use and CO₂ emission

To understand the evolution in total energy use and
Fig. 3 Intensity of energy consumption and CO₂ emissions at per capita level

Fig. 4 Per capital energy consumption and CO₂ emission in different groups of households in 2002

Fig. 5 Impact of changes in structure, intensity, activity and household of household energy use

Fig. 6 Impact of changes in structure, intensity, activity and household of household CO₂ emission

The related CO₂ emission of households during the period 1992-2002, we related the changes in energy use that have occurred to four factors: (i) change in the energy intensity of consumption (energy intensity effect); (ii) change in the structure of household expenditure (structure effect); (iii) change in per household of consumption activities (activity effect); and (iv) changes in total household number (household effect). For the changes in CO₂ emission we add one more factor: (v) change in the CO₂ intensities of energy use (CO₂ intensity effect). The analyses used to decompose the effects of changes in intensity, structure, activity and household on energy use and CO₂ emission for eight consumption categories by a complete decomposition approach --- the log mean Divisia index method (Ang, 2004) are

\[
E = \sum_{i=1}^{8} E_i \times \frac{\text{Exp}_i}{\text{Exp}_i} \times \frac{\text{Exp}}{H} \times H
\]  

(3)

where \( E \) and \( C \) refer to total household energy use and the associated CO₂ emission respectively, \( E_i \)/Exp is the energy intensity of expenditure on \( i \) consumption category. Exp \( i \)/Exp \( i \) the share of expenditure of \( i \) category in total household expenditure, Exp \( i \)/H is per household consumption expenditure, \( H \) refers to total household number, and Ci/\( E_i \) is CO₂ intensity of energy on \( i \) consumption category.

By using the logarithmic mean weighting scheme from Ang et al. (1998), the difference in the energy use and CO₂ emission between different years can be further decomposed as

\[
\Delta E = E_1 - E_2 = \Delta E(\text{energy}) + \Delta E(\text{structure}) + \Delta E(\text{activity}) + \Delta E(\text{household})
\]

\[
\Delta C = C_1 - C_2 = \Delta C(\text{CO₂}) + \Delta C(\text{energy}) + \Delta C(\text{structure}) + \Delta C(\text{activity}) + \Delta C(\text{household})
\]

(5)

(6)

Results of decomposition of changes in total household energy use from 1992 to 2002 are presented in Fig. 5 and Fig. 6. It is clear from these
figures that increases in consumption activity were the largest contributor to the increases in household energy use and household number were most responsible for the rise of household CO₂ emission. The results also indicate that changes in expenditure structure, energy intensity and CO₂ intensity exerted an upward pull or downward push to the rising in energy use and CO₂ emission in different period.

CONCLUSIONS

This paper investigates the direct and indirect household energy use and associated CO₂ emissions in China. Further we highlight the impact of urban and rural resident’s lifestyle and the changes of energy use and associated CO₂ emissions by structure, activity, intensity and household in the period of 1992-2002. The results indicate that the total amounts increased slightly during this period. More than 55% of household energy use and 58% of household CO₂ emissions were indirect. Thus in the household sector, indirect energy use and CO₂ emissions should be paid more attentions in implementing energy conservation and GHG mitigation policies.

The results quantify conclusively that residents’ lifestyle can have an important and significant impact on energy use and CO₂ emissions. Thus the changes of lifestyle and household consumption behaviors should be considered as one of the most efficient measures for sustainable household consumption.

The paper makes a first step towards the understanding of the causes of household energy use and associated CO₂ emissions changes in China, the explanation for these changes lies in a combination of expenditure structure changes and rising in household expenditure and household number, which offset the benefits gained by energy efficiency improvement. Future researches will provide more insight into the driving forces of household energy use and associated CO₂ emissions.

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NOTES


REFERENCES


