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Zhen-Hua Feng
Le-Le Zou
Yi-Ming Wei

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Center for Energy and Environmental Policy Research
Beijing Institute of Technology
No.5 Zhongguancun South Street, Haidian District
Beijing 100081
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Yi-Ming Wei
Director of Center for Energy and Environmental Policy Research, Beijing Institute of Technology

For more information, please contact the office:

Address:
Director of Center for Energy and Environmental Policy Research
Beijing Institute of Technology
No.5 Zhongguancun South Street
Haidian District, Beijing 100081, P.R. China

Access:
Tel: +86-10-6891-8551
Fax: +86-10-6891-8651
Email: ceeper@vip.163.com
Website: http://ceep.bit.edu.cn/english/index.htm

The impact of household consumption on energy use and CO_2 emissions in China

Zhen-Hua Feng [a, b], Le-Le Zou [d], Yi-Ming Wei [b, c,1]

[a] School of Management, University of Science and Technology of China, Hefei, 230026, China
[b] Center for Energy and Environmental Policy Research, Beijing Institute of Technology, Beijing, 100081, China
[c] School of Management and Economics, Beijing Institute of Technology, Beijing, 100081, China
[d] Institute of Policy and Management, Chinese Academy of Sciences, Beijing, 100190, China

Abstract

In this paper, the consumer lifestyle approach is applied to analyze the impact of consumption by urban and rural households on energy use and CO_2 emissions for different regions and income levels in China. Grey Model is used to compare the relationship between energy consumption, consumption expenditure and CO_2 emissions for different lifestyles. The results show that direct energy consumption is diverse for urban households and simple for rural households in China. Direct energy consumption and CO_2 emissions are increasing faster for urban than for rural households. Indirect energy consumption and CO_2 emissions for urban households are much greater than the direct consumption values. The total indirect energy consumption and CO_2 emissions differ by regions and the structures are different, but the latter differences are not obvious. The impact of household income is enormous. Indirect energy consumption and CO_2 emissions are higher for high-income than for low-income households. The structural difference for indirect energy consumption and CO_2 emissions for households with different income levels is significant. The higher the income, the more diverse is the energy consumption and CO_2 emission structure. The structures for indirect energy use and CO_2 emissions are diverse for urban households, but simple for rural households.

Keywords: household consumption; lifestyle; Energy consumption; CO_2 emissions; CLA

1. Introduction

Greenhouse gas emissions caused by household energy consumption have become a focus on a

[1] Corresponding author
Professor Yi-Ming Wei
School of Management and Economics,
Beijing Institute of Technology (BIT)
5 South Zhongguanccun Street, Haidian District,
Beijing 100081, China
Tel./ Fax: 86-10-68911706
E-mail: ymwei@deas.harvard.edu
ymwei@263.net

worldwide basis. The long-term energy consumption policies and measures in China are mainly focused on certain industrial production sectors. However, household energy use represents an important proportion of all energy consumption and CO_2 emissions. Approximately 45–55% of total energy use is influenced by consumer activities [1]. Household energy consumption is closely related to CO_2 emissions. Munksgaard et al. [2] used a decomposition method to analyze the relationship between Danish household consumption and CO_2 emissions from 1966 to 1992. Reinders et al. [3] analyzed household energy consumption in 11 European Union countries and found that household energy consumption varied with expenditure. Household indirect energy demands and spending were linearly related. Pachauri [4] used survey data for 1993–1994 to analyze the impact of household energy consumption in India. The results showed that socio-economic, demographic, geographic, family and residential factors affected energy consumption, with household expenditure and income levels having the greatest impacts. Alfredsson [5] concluded that green consumption could reduce energy use and CO_2 emissions, albeit rather weakly. Bin and Dowlatabadi [6] used the consumer lifestyle approach (CLA) to study the relationship between consumer activities and energy use and related CO_2 emissions. Their results showed that 80% of energy consumption and CO_2 emissions could be attributed to consumer behavior and related economic activities. The indirect effects of consumer behavior caused by energy consumption and CO_2 emissions were twice those of direct actions. Lenzen et al. [7] used input–output analysis to evaluate sustainable household consumption from a global perspective. Their results showed that energy needs are quite different across countries and do not support the Kuznets curve. Rao and Reddy [8] used micro-level data to study changes in household energy use in India. Reddy and Srinivas [9] analyzed Indian household energy consumption patterns and the factors that influence them. Rosas-Floresa and Gálvezb [10] researched the trends in Mexican residential energy use, analysis shown that important factors contributing to the increase include changes in the types of housing built, heating, cooling, water-heating equipment and other appliances. Ouyang et al. [11] studied the rebound effect in the household energy efficiency of China and its related negative influence on the energy demand. Other researchers have focused on the relationship between residential energy use and efficiency effects [12, 13].

China is a typical dualistic society. There are many significant differences between urban and rural areas [14]. Although China has developed very rapidly in recent years, there are still large gaps between urban and rural areas. To investigate the impact of household energy consumption and CO_2 emissions, we studied urban and rural areas separately. Owing to differences in social and economic structures, the energy consumption patterns in urban and rural are very different.

Many factors impact household consumption, energy use and CO_2 emissions, such as region and income [4]. Wei et al. [14] used CLA to quantify the direct and indirect impacts of lifestyle choices by urban and rural households in China on energy use and related CO_2 emissions during 1999–2002. Based on the study by Wei et al. [14], we use CLA [6] to analyze energy consumption and CO_2 emissions for urban and rural households and compare the patterns for different regions and household income levels. Grey relational analysis is used to analyze the relationship between the energy consumption, household consumption expenditures and CO_2 emissions for different lifestyle choices. The research questions include: (1) What are the trends for household energy consumption and CO_2 emissions? (2) What are the relations between household energy consumption and CO_2 emissions for rural and urban households? (3) What

influence do energy consumption and personal consumption expenditure have on CO_2 emissions? (4) What is the impact of regional and income disparities on energy consumption and CO_2 emissions? (5) What lifestyle choices account for the largest proportion of energy consumption and CO_2 emissions?

The remainder of the paper is organized as follows. Section 2 reviews the CLA and grey relational analysis methods used. Section 3 describes the source data. The empirical results are presented in Section 4 and discussed. Conclusions and policy suggestions are proposed in Section 5.

2. Methodology

2.1. CLA method

The term 'consumer' refers to those who purchase and use products and services for individual or household consumption. A lifestyle is a way of living and is reflected in consumption behavior [6].

Based on the work of Bin and Dowlatabadi [6], we compare and analyze consumption patterns for urban and rural households in China and the resulting differences in energy consumption and CO_2 emissions. Households use energy directly, such as for lighting and heating, and consumers need to buy and use a range of products to meet their needs, such as clothing, food, housing and travel. The production and processing of these commodities entail extensive energy consumption [14]. The basic principle of CLA is to decompose all the components of a household's lifestyle. The total energy consumption of households is broken down into a variety of lifestyle areas in Table 1. According to Bin and Dowlatabadi, CLA comprises the following factors [6]:

(1) External environment variables, such as cultural background, social consumption attitudes and technology development, that shape a consumer's decision process.
(2) Individual determinants, such as attitudes, personal preferences and consumption motives, which are personal psychological variables influencing a consumer's decision-making.
(3) Household characteristics, such as size, income, location and housing area, that influence a consumer's decisions.
(4) Consumer choices, such as purchases and the use of services and equipment.
(5) Consequences, such as energy use and related environmental changes, resulting from consumer behavior.

The external environment has the greatest impact on consumer behavior. External environmental factors, which are very wide in scope, are closely related to long-term accumulation of social factors that include culture, history, consciousness and concepts. Personal decision factors for urban and rural households in China, which are not significantly different among groups in this study, are mainly decided by living environment and family traditions. Here we analyze the impact of factors (3), (4) and (5).

Table 1 Categorization of household living behavior

Category	Urban households	Rural households
Direct influence	Home energy use including lighting, cooking, heating, etc.	Home energy use including lighting, cooking, heating, etc.

Indirect influence	Food; clothing; residence; household facilities, and services; medicine and medical services; transport and communication services; education, cultural and recreation services; miscellaneous commodities and services	Food; clothing; –*; household facilities, and services; medicine and medical services; transport and communication services; education, cultural and recreation services; miscellaneous commodities and services

*Not including residence energy consumption for rural households. Categories according to Bin and Dowlatabadi [6] and Wei et al. [12]

Using the CLA method defined above, we calculated the energy consumption and CO_2 emissions for urban and rural households in different categories.

For direct energy consumption and CO_2 emissions, data on household energy use, including lighting, cooking and heating, were taken from China Energy Statistical Yearbooks [15-19]. CO_2 emissions arising from direct energy consumption were calculated as:

$$CO_2\_direct = F\_m \times CO_2\_coefficient, \quad (1)$$

where F_m is a matrix of energy consumption. Here we consider five fuels: coal, petroleum, natural gas, electricity and heat. Thus, *F_m* is a 1×5 vector-matrix. $CO_2\_coefficient$ is a 1×5 matrix of CO_2 coefficients for fuels.

Indirect energy consumption is related to the purchase and use of products to meet a consumer's needs, such as clothing, food and residences. The production processes for these commodities entail extensive energy consumption (Table 1) [6].

According to Bin and Dowlatabadi [6] and Wei et al. [14] and taking into account data in China Statistical Yearbooks [15–19] and China Energy Statistical Yearbooks [20–23], we linked the eight categories to production sectors, as shown in Table 2, to calculate indirect energy consumption and CO_2 emissions[2].

Table 2 Sectors in the China Energy Statistical Yearbooks related to consumer expenditure

Number	Consumer expenditure	Related sectors
1	Food	Food processing, food and beverage production
2	Clothing	Textile industry, garments and other fiber products, leather, furs, down and related products
3	Residence	Production and supply of electric power, steam and hot water, gas, and tap water, construction, non-metal mineral and metal products
4	Household facilities, articles and services	Timber processing, bamboo, cane, palm fiber and straw products, furniture manufacturing and electronic equipment and machinery
5	Medicine and medical services	Medical and pharmaceutical products
6	Transport and communication services	Electronic, telecommunications and transportation equipment
7	Education, cultural and recreation services	Papermaking and paper products, printing and record medium reproduction, and cultural education and sports articles

[2] When discussing the impact of rural household consumption on energy use and CO_2 emissions, the paper do not consider the impact of the residence. The rationale for this decision lays in the fact that the end-use energy shown in Construction in China Energy Statistical Yearbook did not contain energy use of rural construction.

According to Table 2, we calculated the intensity for energy consumption and CO_2 emissions for each consumer spending category as:

$$E\_indirect\_urban = EI \times X \times P\_urban, \quad (2)$$

$$E\_indirect\_rural = EI \times X \times P\_rural, \quad (3)$$

$$CO_2\_indirect\_urban = CI \times X \times P\_urban, \quad (4)$$

$$CO_2\_indirect\_rural = CI \times X \times P\_rural. \quad (5)$$

The variables are defined in Table 3.

Table 3 Indirect energy use variables

$E\_indirect\_urban$	Indirect energy consumption by urban households	10000 ton coal equivalent (tce)
$E\_indirect\_rural$	Indirect energy consumption by rural households	10000 ton coal equivalent (tce)
$CO_2\_indirect\_urban$	Indirect CO_2 emissions by urban households	10000 ton CO_2
$CO_2\_indirect\_rural$	Indirect CO_2 emissions of rural households	10000 ton CO_2
EI	1×8 matrix of energy intensity	tce/10^4 CNY
CI	1×8 matrix of CO_2 intensity	ton CO_2/10^4 CNY
X	8×1 matrix of consumer expenditure	CNY/person
P_urban	Number of urban residents	10000 persons
P_rural	Number of rural residents	10000 persons

2.2. Grey relational analysis

Grey relational analysis was used to solve the following problem. As the economy develops, lifestyle categories affect CO_2 emissions: what energy consumption and CO_2 emissions trends for lifestyle categories have the greatest effect? Grey relational analysis is based on the sequence similarity of the geometry of curves to determine the closeness of a link. The closer the link, the greater is the corresponding sequence correlation. The theory, which was proposed by Deng [24, 25], is applied in many fields [26–28]. Here we apply the theory to analyze: (1) the relations between indirect energy consumption for different lifestyles and indirect CO_2 emissions; and (2) the relations between household consumer expenditure and indirect CO_2 emissions. Grey relational analysis was carried out as follows.

Assume that X_i is an indirect energy consumption sequence, $X_i = (X_{i1}, X_{i2}, \cdots, X_{in})$, where i

denotes lifestyle category (food, clothing, residence, household facilities, articles and services, medicine and medical services, transport and communication services, education, cultural and recreation services, miscellaneous commodities and services) and *n* is the year. X_0 is the sequence for indirect CO_2 emissions, $X_0 = (X_{01},\ X_{02},\cdots,\ X_{0n})$. $\Delta_i(k) = \left|X_0(k) - X_i(k)\right|$ is the absolute difference in CO_2 emissions $X_0(k)$ and indirect energy consumption $X_i(k)$ at time *k*. The correlation coefficient at *k* is:

$$\xi_i(k) = \frac{\min\limits_i \min\limits_k \left|X_0(k) - X_i(k)\right| + \rho \max\limits_i \max\limits_k \left|X_0(k) - X_i(k)\right|}{\left|X_0(k) - X_i(k)\right| + \rho \max\limits_i \max\limits_k \left|X_0(k) - X_i(k)\right|},\ \ \rho \in [0,1]. \quad (6)$$

ρ reflects the focus of the gap between CO_2 emissions and indirect energy consumption; the gap is $\max\limits_i \max\limits_k \left|X_0(k) - X_i(k)\right|$ for ρ =0.5 [29].

$\gamma_i = \frac{1}{n}\sum_{j=1}^{n} \xi_i(K)$ is the grey relational grade for indirect energy consumption and CO_2 emissions for lifestyle class *i*. The relational grade for energy consumption and CO_2 emissions is $r = (\gamma_1,\ \gamma_2,\cdots,\ \gamma_n)$. We can analyze the relational grade for energy consumption and CO_2 emissions according to the size of *r*.

2.3. Data

Data for direct energy consumption by households and final energy consumption by different sectors are all taken from China Energy Statistical Yearbooks for 2004–2008 [15–19]. Data on gross outputs for different sectors, consumption expenditure for urban and rural households, and the population of urban and rural regions are all taken from China Statistical Yearbooks for 2005–2008 [20–23]. Regions and household income levels are classified according to China Statistical Yearbooks for 2006–2008 [21–23]. CO_2 coefficients for coal, oil and natural gas are from Zhang [30]. CO_2 coefficients for electricity and heat are based on calculations according to China Energy Statistical Yearbooks for [17–19]. We calculate the conversion rate for consumption of fossil energy transformed into heat and electric power and get the CO_2 coefficients[3].

4. Results and discussion

4.1. Direct impact of household lifestyle on energy use

[3] We do not consider the electric power from nuclear power, for the share is small in China (only 0.97% in 2007).

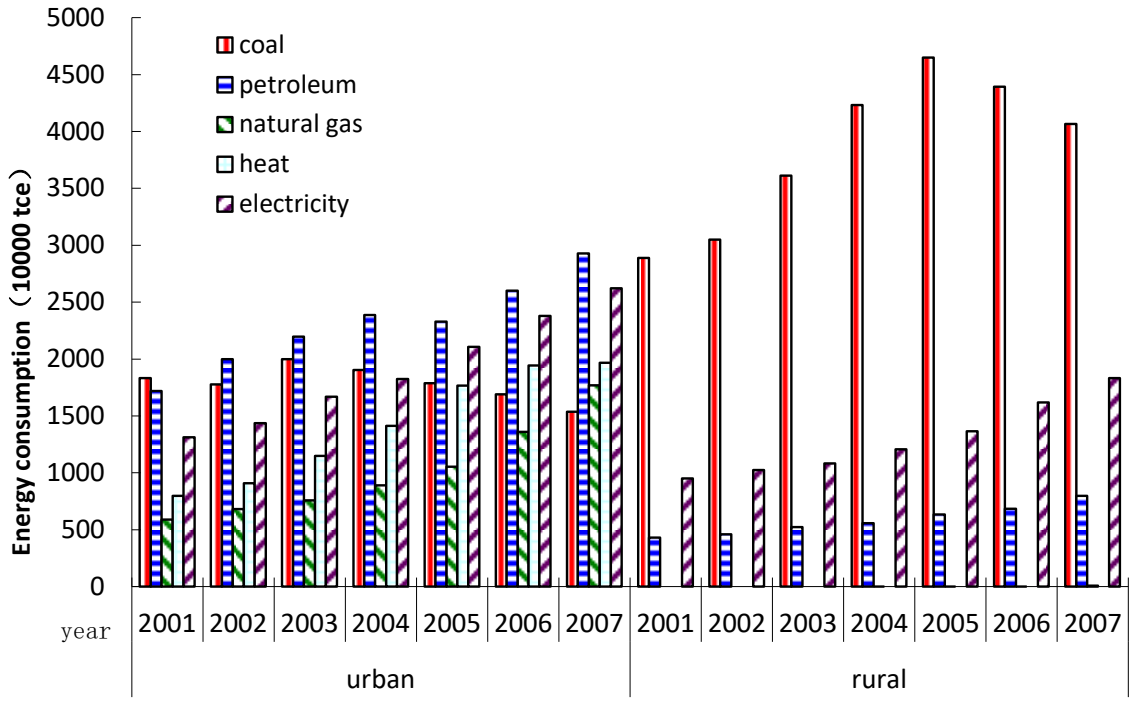


Fig. 1. Direct impact of household lifestyle on energy use during 2001–2007.

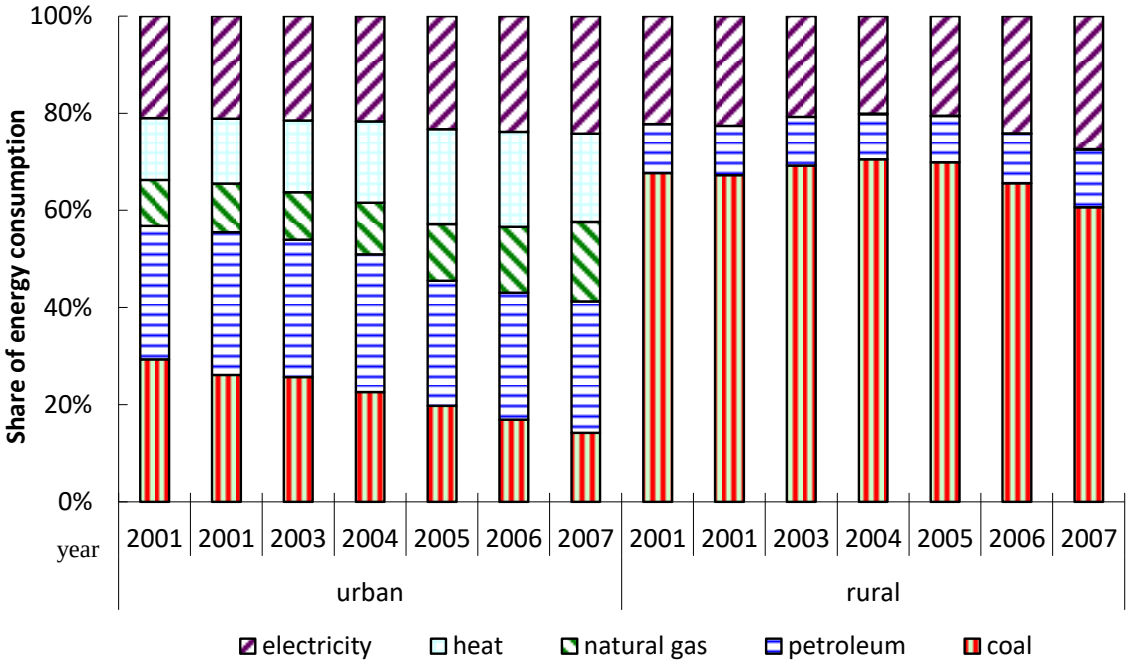


Fig. 2. Direct impact of urban and rural household lifestyle on percentage energy use during 2001–2007.

Direct energy consumption by urban households in China is diverse. The proportion of coal decreased year by year. The energy consumption structure in rural areas is simple and is dominated by coal. The direct energy consumption of urban and rural households is mainly determined by energy accessibility. Urban households have greater access to efficient and cleaner energy. As shown in Figs. 1 and 2, for urban

households the proportion of coal used for energy consumption decreased during 2001–2007 and the proportion of petroleum increased to its highest level. The proportions of electricity, heat and natural gas increased, indicating total energy use in urban households was in transition.

The source for direct energy consumption in rural areas is mainly coal. Although the proportion of coal used has decreased since 2004, the rate of decrease has been slow. The proportion of coal used was more than 60% in 2007. The proportion of electricity used increased and that of oil decreased. The proportion of natural gas used was almost 0. The energy structure is simple. Household energy consumption for tasks such as cooking in most rural regions typically depends on the direct use of coal, which has very low thermal efficiency and is wasteful. Approximately 30% of coal briquettes are used for cooking [31]. Thus, the challenge is to improve the energy efficiency and energy structure in rural regions to reduce energy consumption and CO_2 emissions.

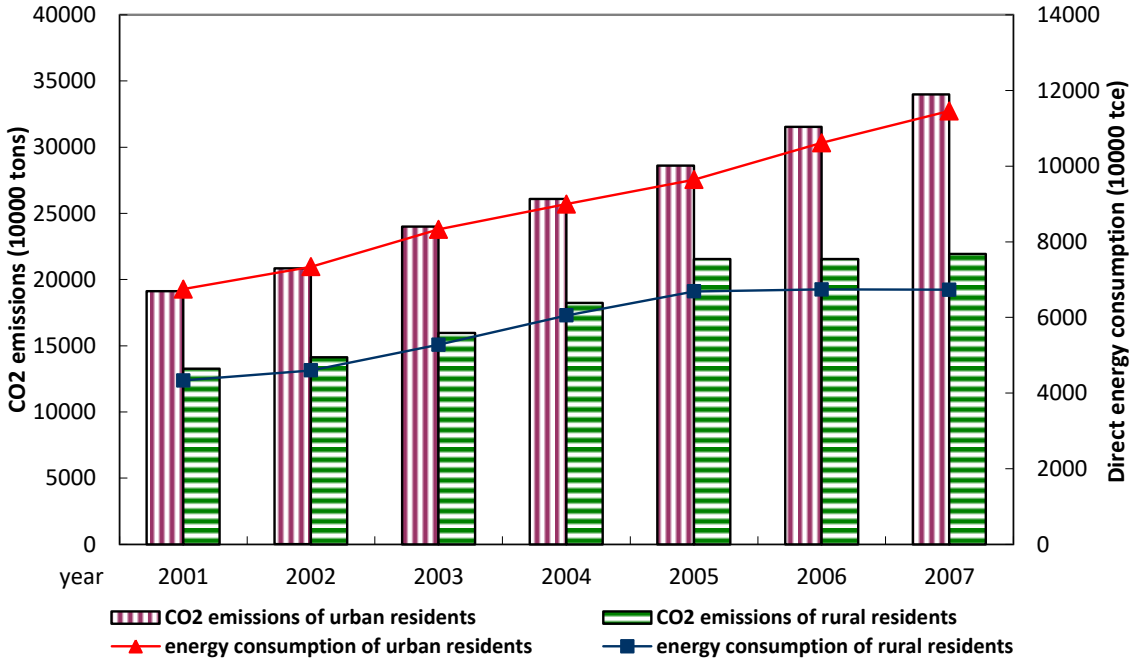


Fig. 3. Direct energy consumption and CO_2 emissions for urban and rural households during 2001–2007.

Direct energy consumption and CO_2 emissions by urban households increased at a faster rate than for rural households during 2005–2007 (Fig. 3). Energy consumption was greater for urban than for rural households for the following reasons.

(1) The variety and quantity of home electrical and heating devices are much greater for urban than for rural households. Recent rapid economic development has led to an increase in the use of electrical appliances and air conditioning in urban households. The number of air conditioners per 100 urban households in 2007 was three times that in 2000, and the number of computers increased 5.5 times [23]. These would greatly increase energy consumption and CO_2 emissions. However, the number of air conditioners per100 rural households was less than one-tenth of the number for urban households, and the number of computers was about one-fifteenth [23].

(2) Rural households use crop residue biomass and biogas for energy as well as commercial energy sources. Crop residues and biogas are not counted in the official statistics, which leads to some deviations [14].

(3) The ratio of rural to urban populations in China decreased from 1.66 in 2001 to 1.23 in 2007 [23] and increased urbanization and rural depopulation led to higher energy consumption. In addition, in recent years the number of migrant workers increased, which increased energy consumption in urban areas and reduced it in rural areas.

4.2. Indirect energy consumption and CO_2 emissions in relation to lifestyle

Indirect energy consumption by households is relatively large. The results for direct and indirect energy consumption and CO_2 emissions during 2005–2007 are compared in Fig. 4.

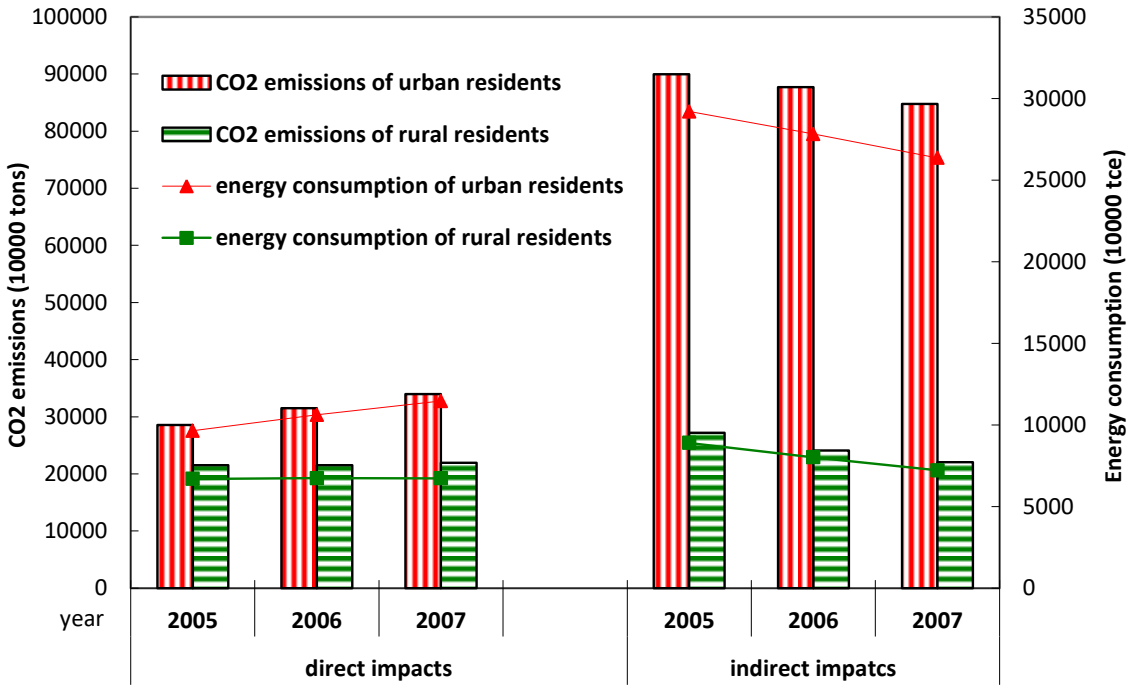


Fig. 4. Comparison of direct and indirect impacts on energy consumption and CO_2 emissions for households during 2005–2007.

Indirect energy consumption and CO_2 emissions for urban households were much higher than the corresponding direct values, but no significant difference was observed for rural households. The overall household energy consumption efficiency increased. Indirect energy consumption and CO_2 emissions for urban and rural households have decreased slightly as a result of improvements in energy efficiency in China during 2005–2007. Household indirect energy consumption can mainly be attributed to commodities such as clothing, food and housing. High levels of energy consumption and CO_2 emissions arise from commodity production, conversion and distribution. All industry sectors related to households are shown in Table 2. Energy consumption has decreased in recent years, whereas value-added industry has increased

[21–23] and energy efficiency has greatly improved. Energy consumption and CO_2 emissions arising from household consumption decreased during 2005–2007. In addition, indirect CO_2 emissions were greater than direct emissions for urban households. Urban household lifestyle is related to many industrial sectors, such as housing, electricity and hot water production, which require large amounts of energy. The development of education and entertainment is greater in urban than in rural areas, so energy consumption and CO_2 emissions for the education, culture and entertainment category were greater for urban households. Thus, overall energy consumption was much higher for urban than for rural households. Moreover, the results indicate that household behavior is closely related to industrial production sectors, and the impact of an urban lifestyle on energy consumption and CO_2 emissions is greater.

4.3. Impact of household lifestyle on indirect energy use and related CO_2 emissions

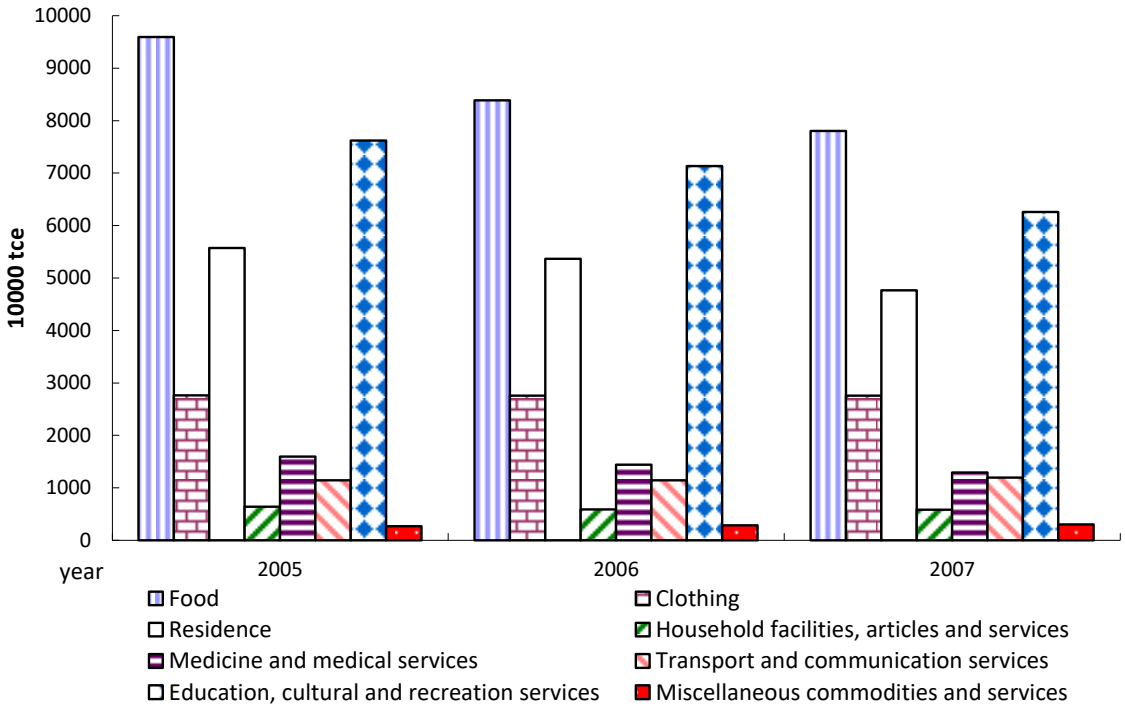


Fig. 5. Impact of urban household lifestyle categories on indirect energy use during 2005–2007.

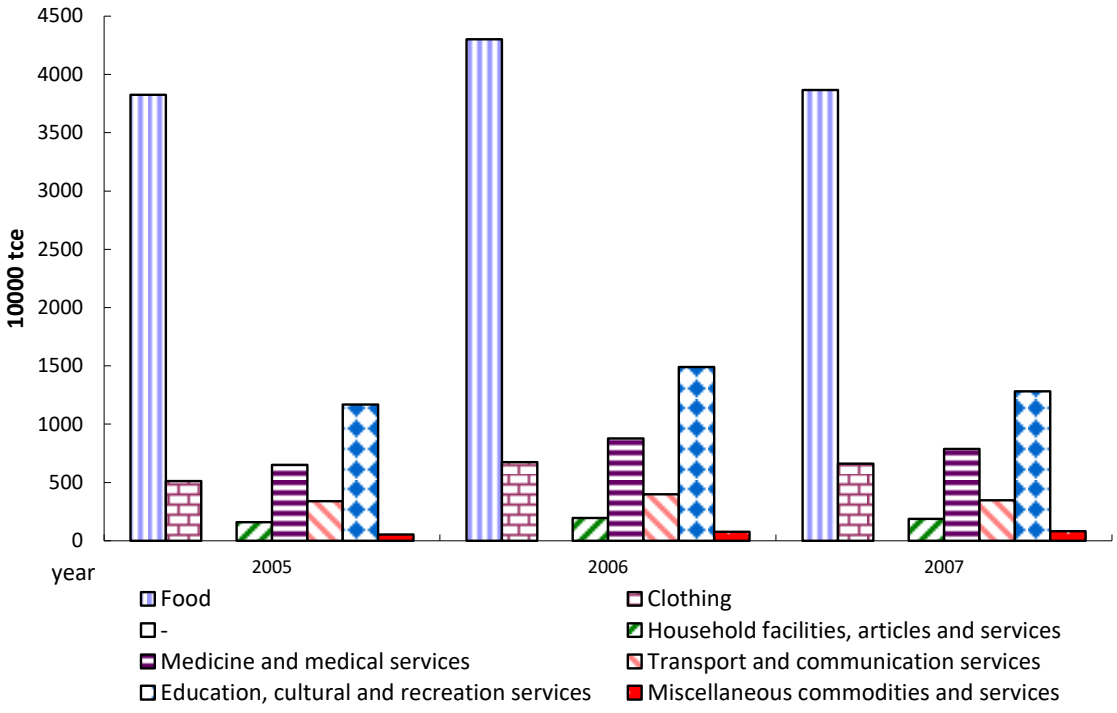


Fig. 6. Impact of rural household lifestyle categories on indirect energy use during 2005–2007.

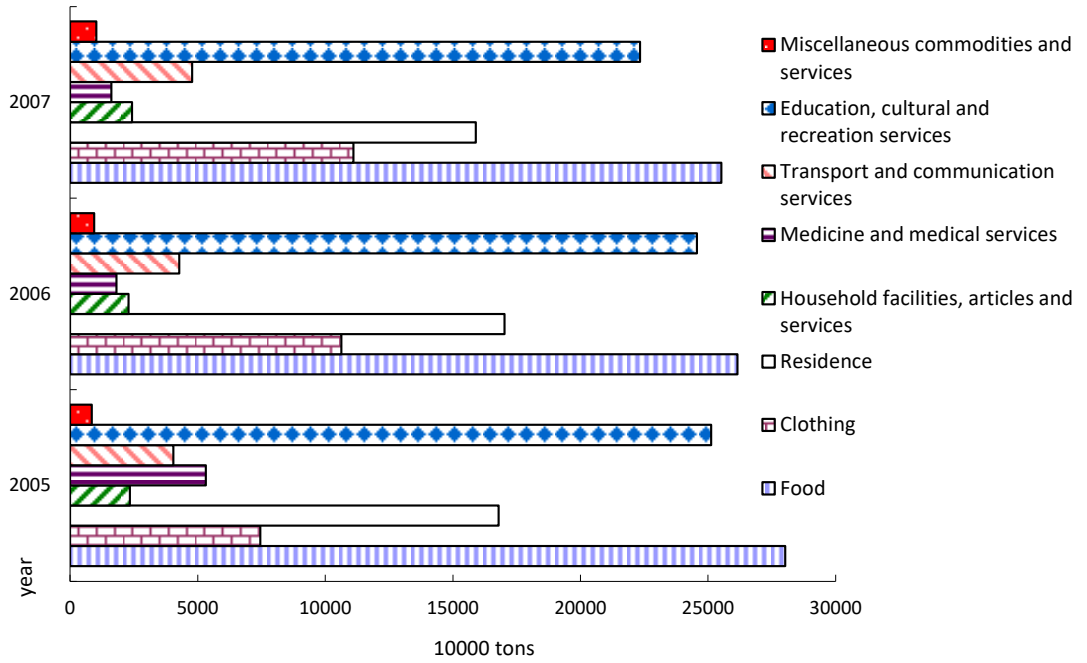


Fig. 7. Impact of urban household lifestyle categories on indirect CO_2 emissions during 2005–2007.

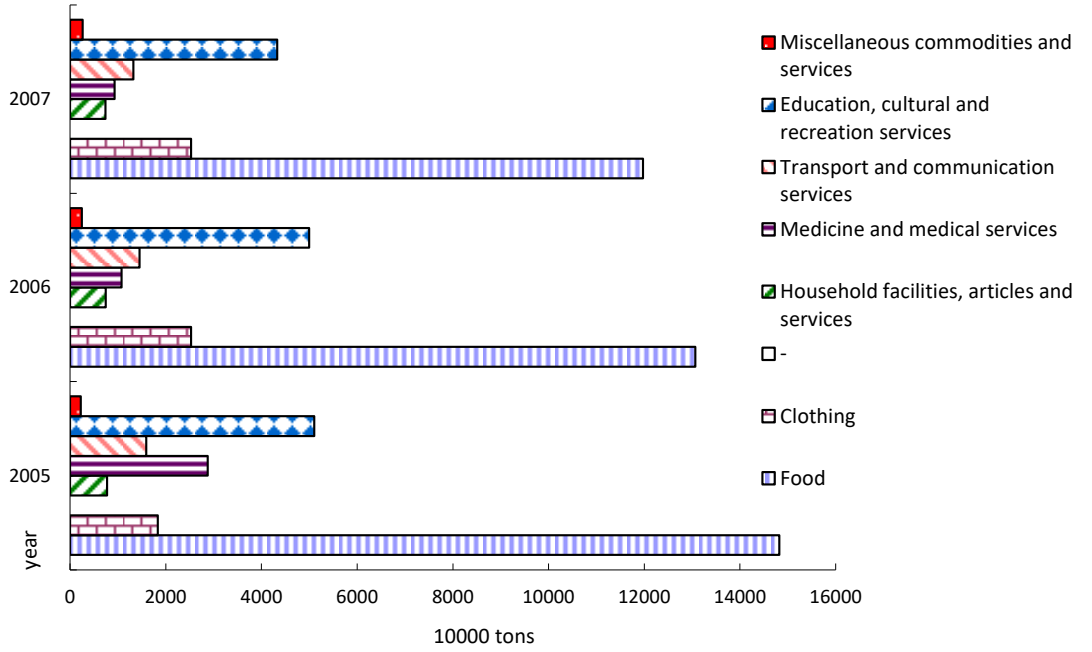


Fig. 8. Impact of rural household lifestyle categories on indirect CO_2 emissions during 2005–2007.

Lifestyles in Chinese urban households are diverse. The most energy-intensive choices by urban households are food, clothing, residence, and education, cultural and recreation services (Figs. 5 and 7). Food accounts for the greatest proportion of indirect energy consumption and CO_2 emissions for rural households, with household facilities, articles and services, medicine and medical services, transport and communication services, miscellaneous commodities and services accounting for relatively less. For urban households, the residence category is related to electricity and hot water supplies, which consume large amounts of energy for production and transportation. Cultural and recreation services including paper production require high energy consumption. Figs. 6 and 8 show that for rural households, the greatest indirect energy consumption can be attributed to food, accounting for 54.43%, 54.18% and 54.22% in 2005, 2006 and 2007, respectively. Education, cultural and recreation services accounted for 18.74%, 20.71% and 19.60% in 2005, 2006 and 2007, respectively. The proportions for clothing, household facilities, articles and services, medicine and medical services, transport and communication services, miscellaneous commodities and services were relatively less.

The category accounting for the greatest energy consumption and CO_2 emissions was food in both urban and rural areas. The proportion for food was less for urban than for rural areas. The Engel coefficient was lower for urban than for rural households during 2005–2007 (Fig. 9), confirming that lifestyle is more diverse for urban than for rural households.

In addition, indirect energy consumption for the main categories (food, education, cultural and recreation services, household facilities) in urban households decreased by 22.3%, 21.84%, and 16.85% in 2005, 2006 and 2007, respectively. Corresponding related CO_2 emissions decreased by 9.79%, 12.48% and 5.57% (Table 4), while urban household lifestyle improved.

According to the above analysis, for urban households, we should improve energy efficiency to reduce

electricity and heat use; at the same time, the energy efficiency for electricity, heat and steam production and steam transportation should be improved to reduce energy waste. With increasing per capita disposable income [22,23], household consumption has increased. Along with increases in education, culture, clothing and other needs, the entertainment industry has rapidly developed. The number of computers is increasing, with effects on energy consumption and CO_2 emissions. Therefore, lifestyle in China should be guided towards rational and appropriate consumption rather than promoting extravagance. To avoid waste, new technology should be used to reduce the energy demands of the paper industry.

Table 4. Indirect CO_2 emissions for household lifestyle categories during 2005–2007 (tons/10000 CNY)

Year	Food	Education, cultural and recreation services	Residence
2005	1.71	4.07	3.69
2007	1.19	2.83	2.73

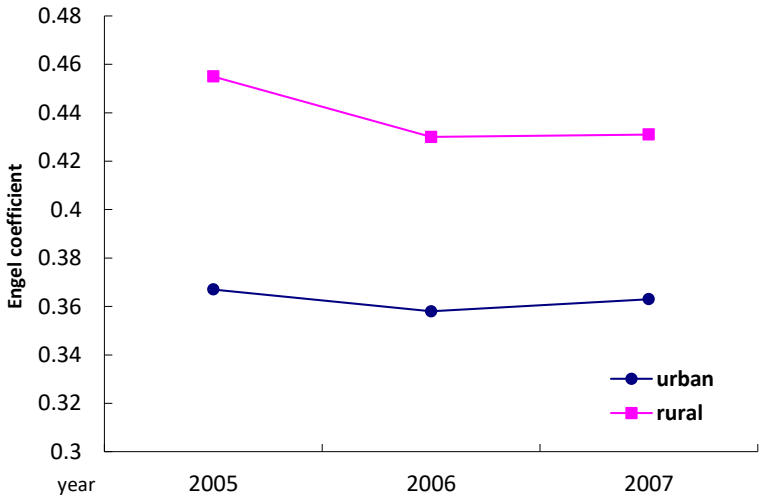


Fig. 9. Engel coefficients for urban and rural households during 2005–2007.

We used grey relational analysis to investigate the relation between indirect CO_2 emissions and indirect household energy consumption. The results are shown in Table 5.

Table 5. Grey relational analysis of indirect CO_2 emissions for indirect household energy consumption

Lifestyle category	Relational grade	
	Urban	Rural
Food	0.6203	0.7463
Clothing	0.7999	0.6266
Residence	0.7940	–
Household facilities, articles and services	0.7897	0.6678
Medicine and medical services	0.6456	0.6353
Transport and communication services	0.7354	0.7226
Education, cultural and recreation services	0.7011	0.6772
Miscellaneous commodities and services	0.6181	0.5755

Indirect CO_2 emissions are closely related to indirect energy consumption. The coefficients for the relational grade in Table 5 are greater than 0.6, indicating that the trends for energy consumption and CO_2 emissions as a function of household lifestyle are similar. However, the relational grades are not the same, indicating that the growth trends for indirect energy consumption and CO_2 emissions are somewhat different.

Living environments and lifestyles affect CO_2 emissions. From a lifestyle point of view, the relational grades for clothing, residence, and household facilities, articles and services for urban households are all close to 0.8, while those for transport and communication services and education, cultural and recreation services are >0.7. The impact of indirect energy consumption for clothing, residence, and household facilities, articles and services is great for urban households, indicating that the trends for changes in indirect energy consumption and CO_2 emissions by urban households are similar for these categories. The relational grades for food, medicine and medical services and miscellaneous commodities and services are relatively low, at 0.6203, 0.6466, and 0.6181, respectively (Table 5). For rural households the highest relational grade is for food, indicating consistent trends for indirect energy consumption and indirect CO_2 emissions for this category. The grade is also high for transport and communication services. The relational grade for miscellaneous commodities and services is 0.5755 (<0.6).

Table 6. Grey relational analysis of indirect CO_2 emissions for household consumption expenditure

Lifestyle category	Relational grade	
	Urban	Rural
Food	0.7009	0.6825
Clothing	0.6497	0.6292
Residence	0.6765	–
Household facilities, articles and services	0.6461	0.6222
Medicine and medical services	0.7568	0.6087
Transport and communication services	0.6258	0.7346
Education, cultural and recreation services	0.6907	0.6350
Miscellaneous commodities and services	0.6596	0.6123

Comparison reveals that the relational grades for indirect CO_2 emissions and household consumption expenditure are low, in contrast to the relational grades for indirect energy consumption and CO_2 emissions, because the intensity differs for energy and CO_2 emissions. High relational grades are observed for food and medicine and medical services for urban households and for transport and communication services for rural households.

High consumption expenditure does not necessarily lead to high CO_2 emissions, since the latter are also related to lifestyle, energy intensity and emission intensity. The relational grades in Table 6 are less significant than those in Table 5. Household expenditure needs to be converted to energy consumption to have an impact on CO_2 emissions, so reductions in energy and CO_2 intensities are important for reducing energy consumption and CO_2 emissions.

4.4. Impact of regional differences in lifestyle on indirect energy consumption and CO_2 emissions

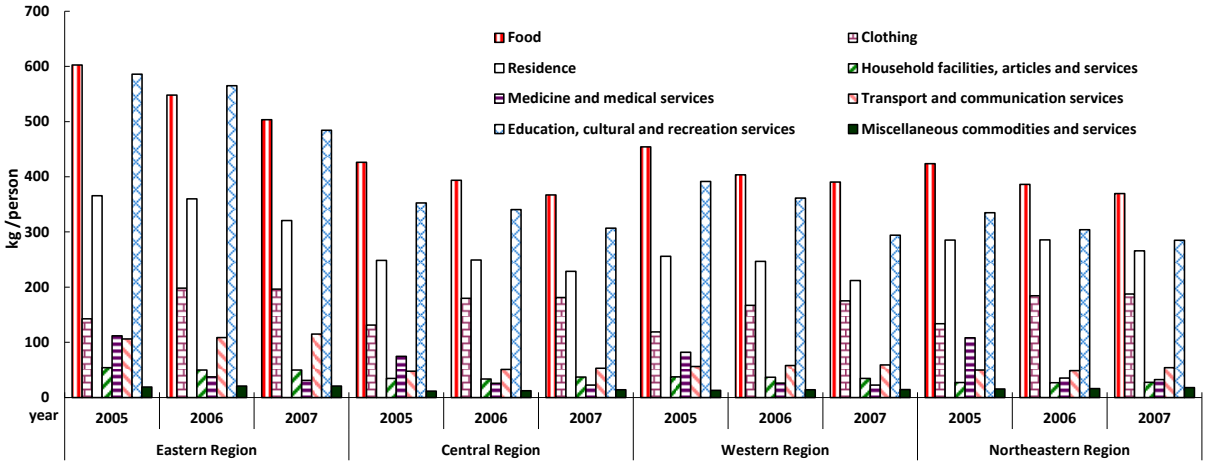


Fig. 10. Indirect CO_2 emissions for urban households by region during 2005–2007.

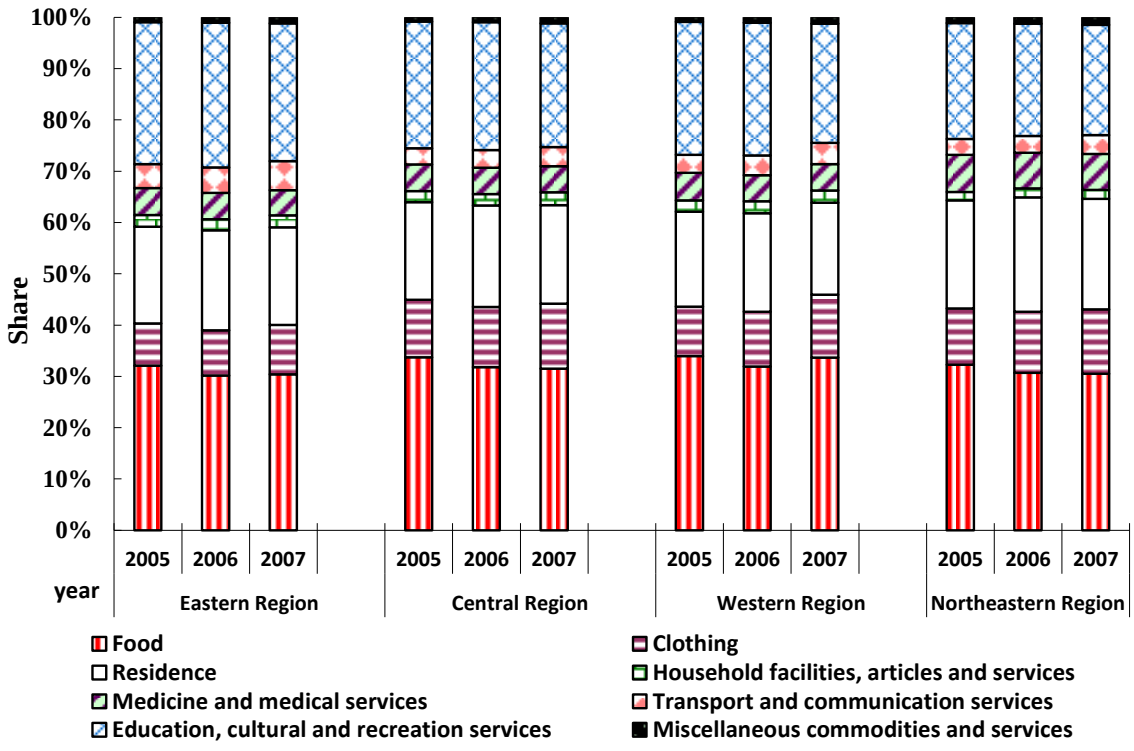


Fig. 11. Impact of lifestyle categories for urban households on indirect energy use by region during 2005–2007.

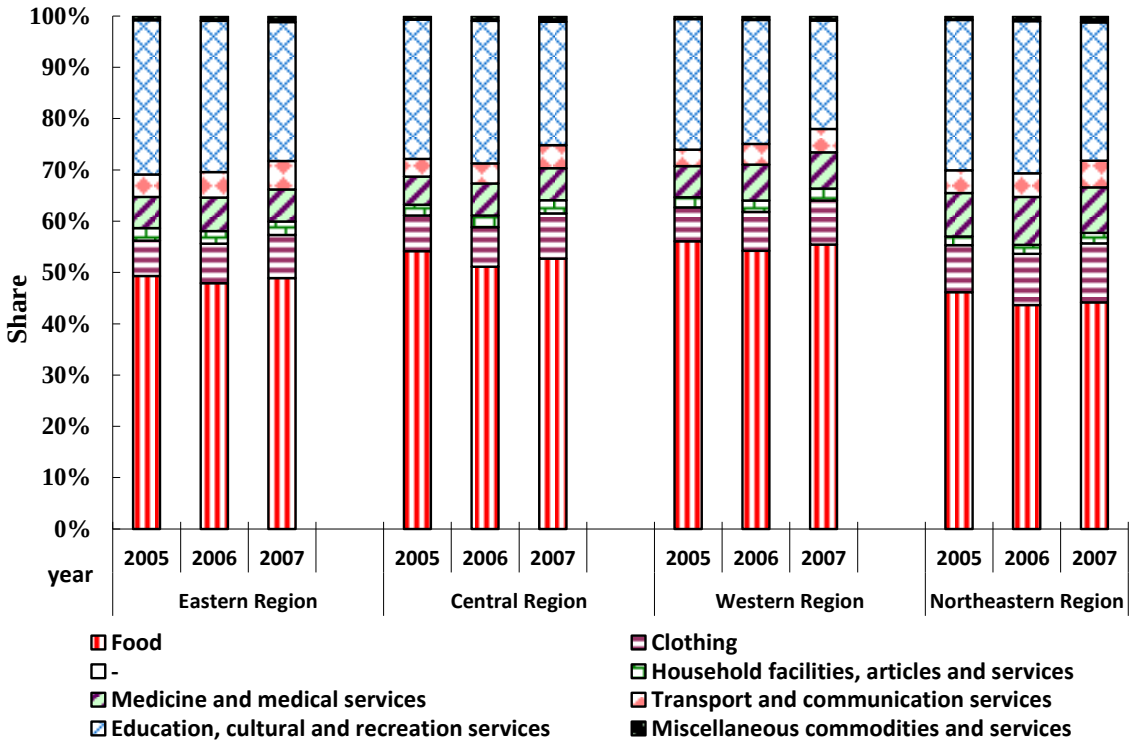


Fig. 12. Impact of lifestyle categories for rural households on indirect energy use by region during 2005–2007.

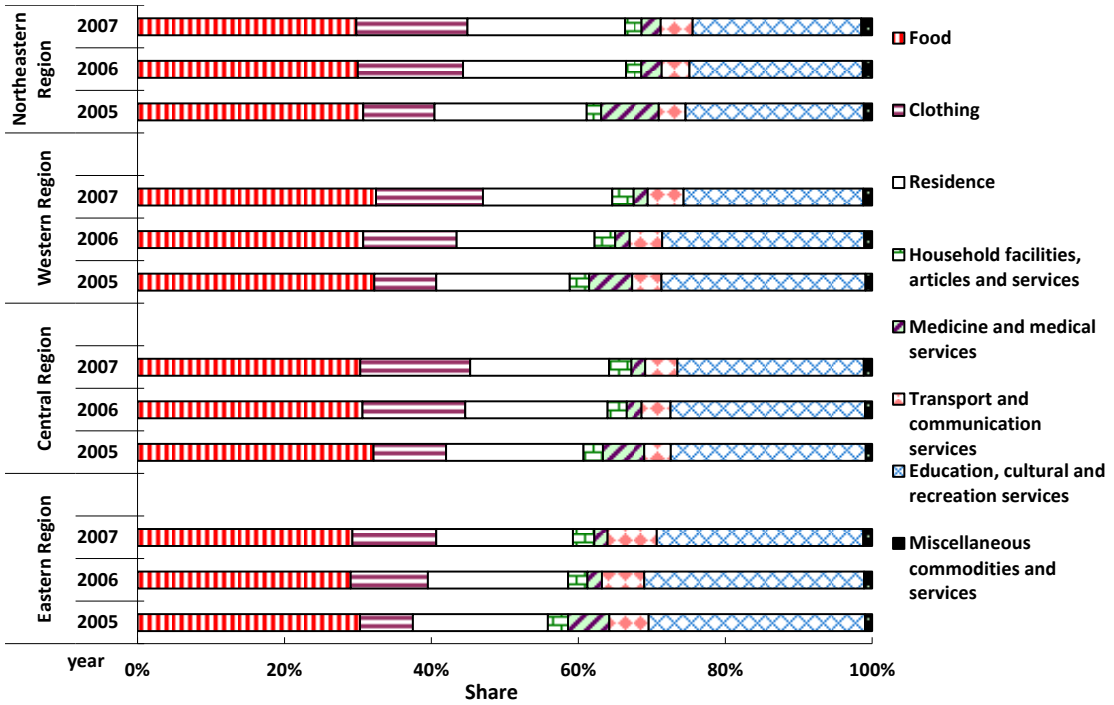


Fig. 13. Impact of lifestyle categories for urban households on indirect CO_2 emissions by region during 2005–2007.

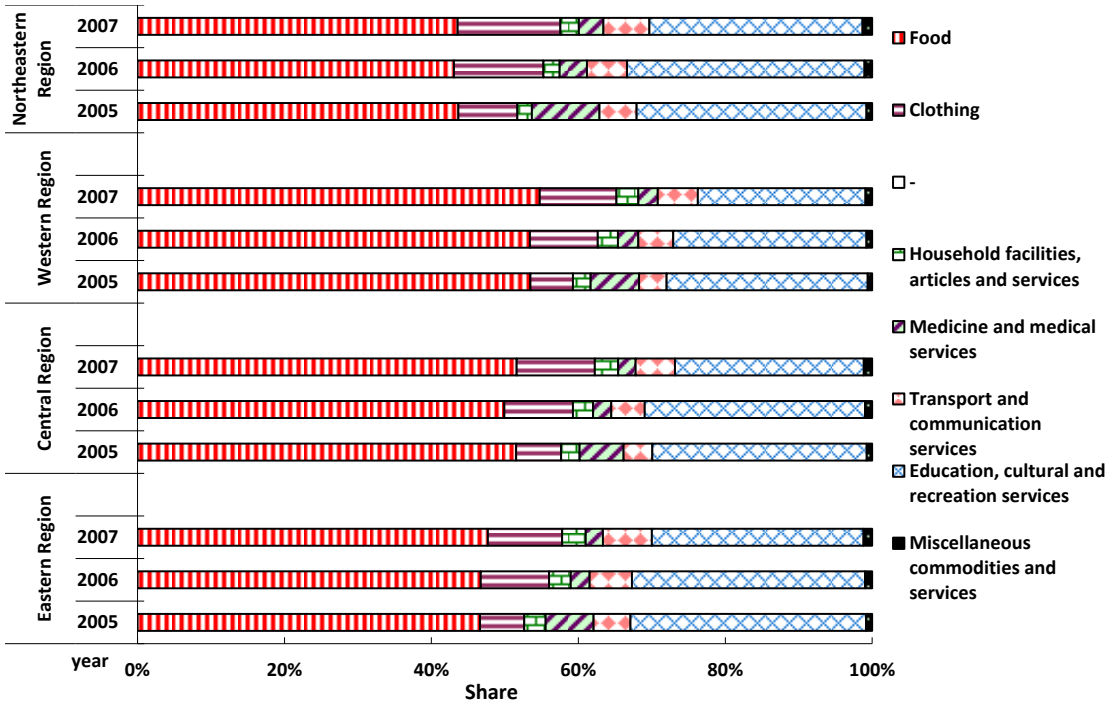


Fig. 14. Impact of lifestyle categories for rural households on indirect CO_2 emissions by region during 2005–2007.

Total indirect energy consumption and CO_2 emissions differ by region. The structures for indirect energy consumption and CO_2 emissions exhibit regional differences, but these are not very obvious. Inter-regional differences in China are mainly reflected in energy consumption and CO_2 emission quantities. The highest urban per capita income was in the Eastern region (16,974 CNY) and the lowest was in the Western region (11,309 CNY) in 2007 [23]. CO_2 emissions for urban households were significantly higher for the Eastern region than for the other regions (Figs. 10 and 15). Differences in energy consumption and CO_2 emission quantities are also evident (Fig. 15). The structures for energy consumption and CO_2 emissions are similar for the regions. The largest proportion of energy consumption and CO_2 emissions for urban households can be attributed to food. Total energy consumption decreased year by year in all regions (Table 7).

Indirect energy consumption in the urban regions is quite different. The largest proportion in the Eastern region can be attributed to education, cultural and recreation services (27% in 2007); whereas food accounts for the largest share in the Western region (34% in 2007). Energy consumption for the residence category is large in Northeast, mostly because of the geographical location and weather conditions. The proportion of energy consumption for clothing increased year by year in all regions (Fig. 11), indicating diversification of lifestyle and improvements in living conditions.

Indirect CO_2 emissions for food, clothing and education, cultural and recreation services decreased significantly in all regions; whereas those for medicine and medical services increased from 2005 to 2007. CO_2 emissions were significantly higher in the Eastern region than in the other three regions. The proportion for education, cultural and recreation services was large in the Eastern region (Fig. 13). CO_2 emissions for household facilities, articles and services increased, indicating that the use of household appliances increased in urban households.

The proportions of indirect energy consumption for food and education, cultural and recreation services in rural households were large in all regions. The largest proportion for food was in the Western region (55% in 2007). The proportions for transport and communication services, clothing and household facilities, articles and services increased (Fig. 12), indicating that regional living levels improved and consumption diversified.

Among the sources of indirect CO_2 emissions, the proportions for clothing, household facilities, articles and services, miscellaneous commodities and services increased year by year in rural regions. The proportion for food increased (Fig. 14), indicating that indirect emissions for the other categories showed a relative decrease.

Although China was divided into four areas, each region is still vast. Therefore, the structures for energy consumption and CO_2 emissions exhibit regional differences, but these are not very obvious. The proportions for food, residence and education, cultural and recreation services are large, indicating that consideration of lifestyle choices for these areas will be key in any energy-saving scheme.

Table 7. Indirect energy consumption in various regions during 2005–2007

	Eastern Region	Central Region	Western Region	Northeastern Region
		Panel A: urban households		
2005	642.59	432.97	457.97	449.86
2006	598.10	407.35	416.16	413.81
2007	534.60	376.13	374.31	391.26
		Panel B: rural households		
2005	170.45	118.33	105.15	128.03
2006	154.25	107.98	90.12	114.61
2007	135.87	95.63	81.27	104.25

Note：The unit is kg coal equivalent per person

4.5. Impact of household income on indirect energy consumption and CO_2 emissions

We analyzed indirect energy consumption and CO_2 emission patterns as a function of the income level of urban and rural households using data in the China Statistical Yearbooks [21–23].

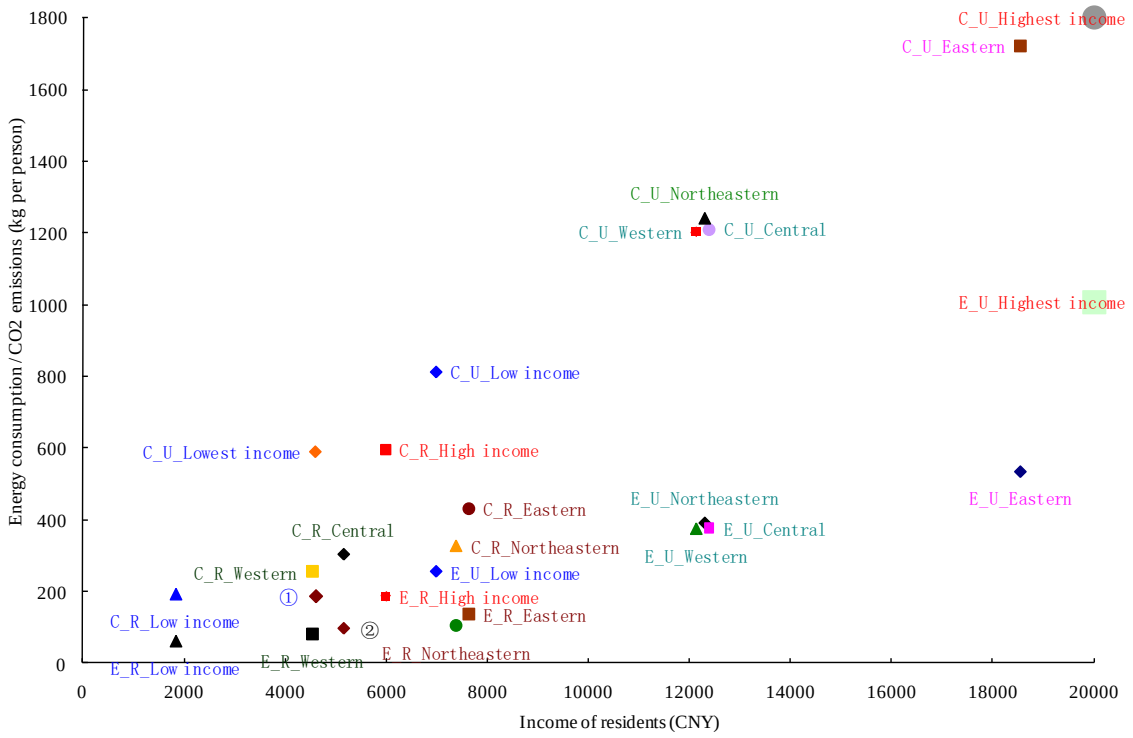
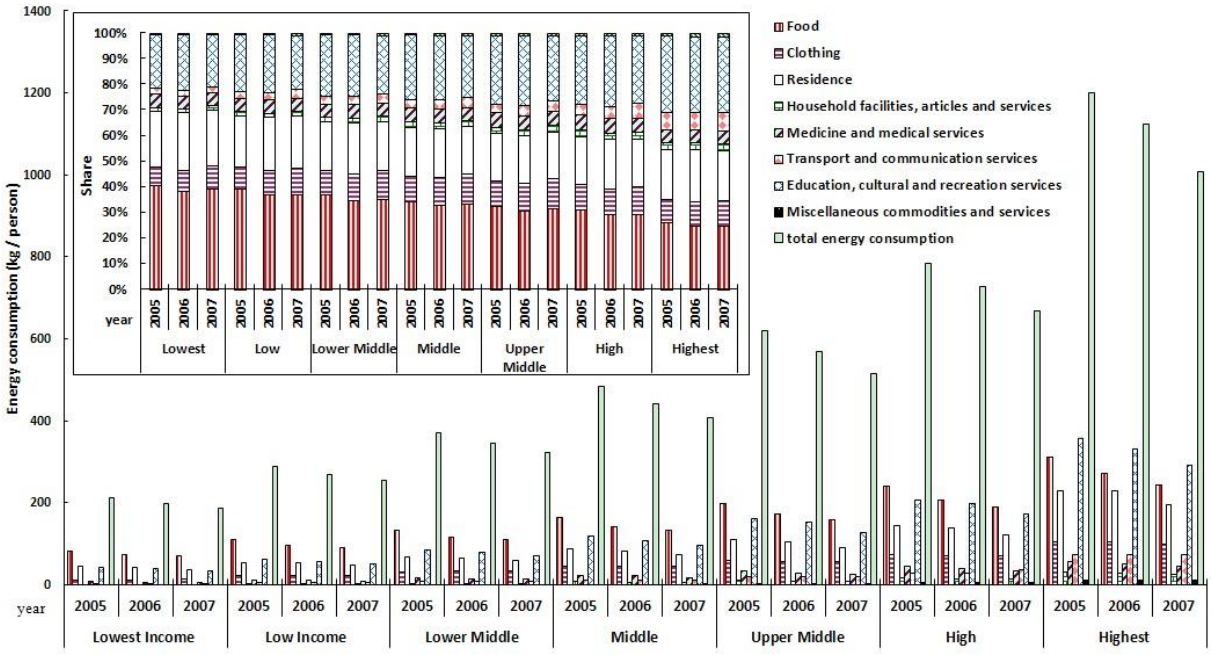


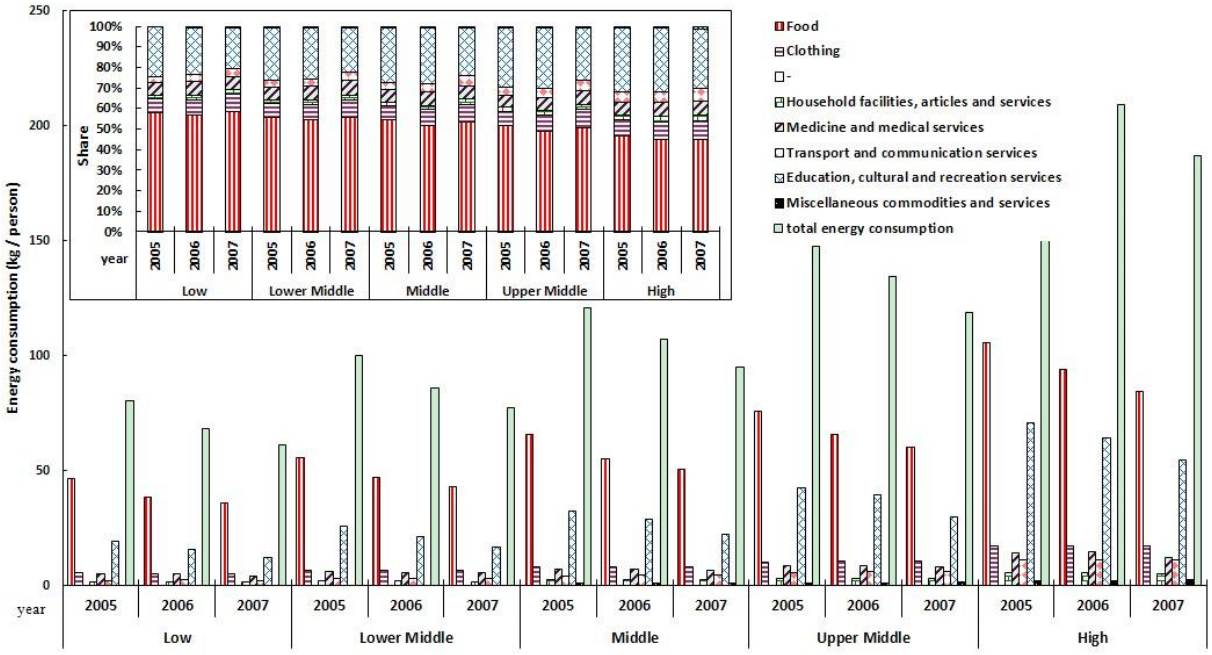
Fig. 15. Indirect energy consumption and CO_2 emissions by region and household income in 2007.

Notes:

① is E_U_Lowest income. ② is E_R_Central. E_U is energy consumption of urban households; E_R is energy consumption of rural households; C_U is CO_2 emissions for urban households; C_R is CO_2 emissions for rural households. E_U_Highest income and C_U_Highest income are 40019 CNY and 3276.72 kg, respectively.

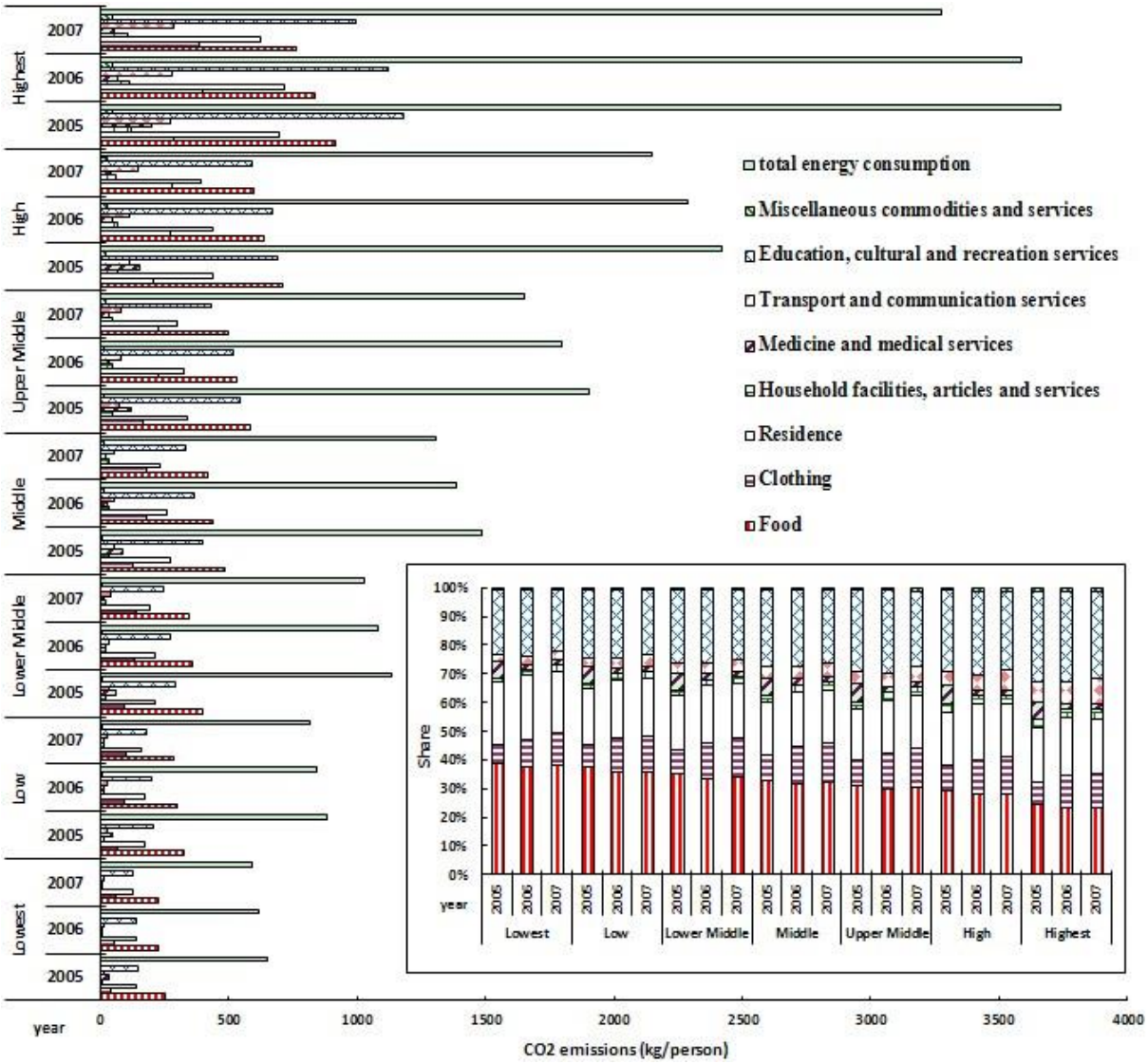


(a)

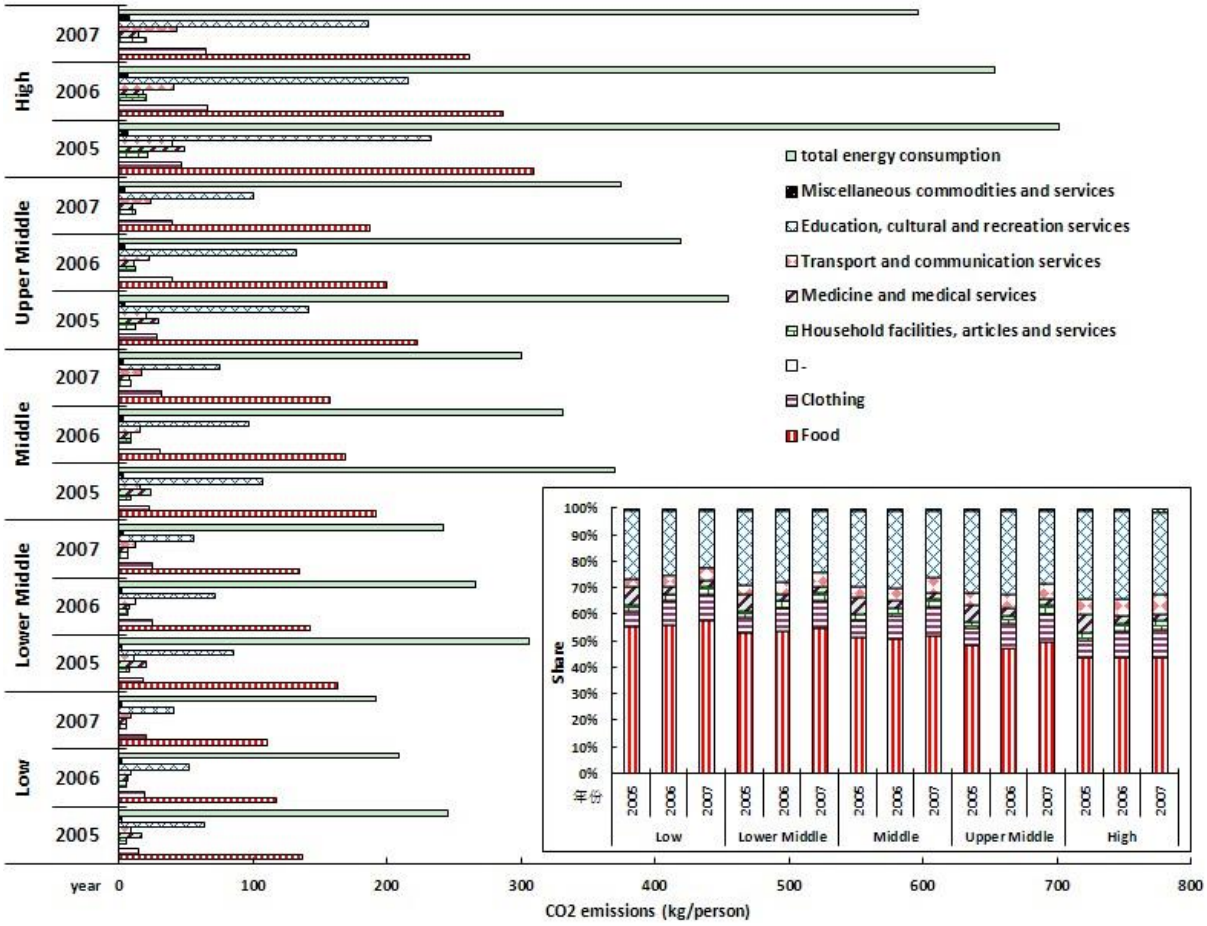


(b)

Fig. 16. Indirect energy consumption by income during 2005–2007 for (a) urban and (b) rural households.


Highest
High
Upper Middle
Middle
Lower Middle
Low
Lowest
2007
2006
2005
total energy consumption
Miscellaneous commodities and services
Education, cultural and recreation services
Transport and communication services
Medicine and medical services
Household facilities, articles and services
Residence
Clothing
Food
Share
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
year
Lowest
Low
Lower Middle
Middle
Upper Middle
High
Highest
year
0
500
1000
1500
2000
2500
3000
3500
4000
CO2 emissions (kg/person)

(a)



(b)

Fig. 17. Indirect CO_2 emissions by income during 2005–2007 for (a) urban and (b) rural households.

Household income affects indirect energy consumption and CO_2 emissions, which were higher for high-income than for low-income households. Indirect energy consumption and CO_2 emissions structures differed by income level. As income increases, household lifestyle choices change and the corresponding energy consumption and CO_2 emissions increase. Average consumption expenditure, energy consumption and CO_2 emissions for urban highest-income households were 5.8, 5.4 and 5.6 times the values for lowest-income households, respectively (Figs. 15, 16 and 17). Average consumption expenditure, energy consumption and CO_2 emissions for rural high-income households were 3.2, 3.0 and 3.1 times the values for low-income households, respectively (Figs. 15, 16b and 17b). Average consumption expenditure, energy consumption and CO_2 emissions for urban highest-income households were 3.9, 4.8 and 5.0 times the values for the corresponding rural households, respectively (Fig. 15). Energy consumption by highest-income urban citizens was equivalent to 5.4 times that by lowest-income urban dwellers and 4.8 times that of high-income rural citizens. People with high income levels usually have high levels of consumption and many high-level commodities are energy-intensive, leading to increases in energy consumption and CO_2 emissions. The structures for energy consumption and CO_2 emissions differed by income level. The higher the income, the more diverse was the structure. The proportion expended decreased for food and increased for education, cultural and recreation services, clothing, transport and

communications services with increasing income (Figs. 15–17).

For urban households, as income increased, the proportion and absolute amount of energy consumption and CO_2 emissions decreased for food and increased for education, cultural and recreation services (Figs. 16 and 17). Energy consumption for food, education, cultural and recreation services decreased from 2005 to 2007. CO_2 emissions for clothing increased from 2005 to 2007 (Figs. 16 and 17).

Compared with urban households, the structures for energy consumption and CO_2 emissions are simpler for rural households, with food accounting for approximately 50% (Figs. 16b and 17). For high-income households, the proportion of energy consumption and CO_2 emissions for food is relatively low. Proportions for education, cultural and recreation services and clothing increased. Absolute CO_2 emissions due to food decreased from 2005 to 2007.

An increase in income has led to diverse lifestyle choices. The proportion of energy consumption increased for clothing, education, cultural and recreation services, partly because electrical products, computers and paper are energy-intensive. Industry sectors such as paper manufacturing need to be improved to reduce energy intensity. The government should encourage the use of energy-efficient products and promote green and low-power electrical appliances. In addition, the government should guide culture and entertainment to avoid wastage.

5. Conclusions

We used CLA and grey relational analysis to investigate energy consumption and CO_2 emission patterns for urban and rural households. The following results were obtained.

(1) The direct energy structure for urban households in China is diverse. The proportion of coal used decreased from 2001 to 2007, and the proportion of petroleum is the largest since 2002. The share of electricity and natural gas increased, indicating that energy use by urban households is in transition. A single-energy consumption structure was observed for rural areas, with coal the main energy source. The energy efficiency of coal is very low, so the energy structure in rural areas needs to be changed.

(2) Direct energy consumption and CO_2 emissions are increasing faster for urban than for rural households. For urban households, indirect energy consumption and CO_2 emissions are much higher than the direct levels. Such differences are not evident for rural households. The efficiency of energy consumption has increased overall for households in China.

(3) Urban lifestyles in China are diverse. The most energy-intensive choices are food, clothing, residence and education, and cultural and recreation services. Food accounts for the major proportion of indirect energy consumption and CO_2 emissions in rural households.

(4) The relationship between indirect CO_2 emissions and indirect energy consumption is close. Different lifestyle choices affect CO_2 emissions.

(5) Total indirect energy consumption and CO_2 emissions differ by region. Structures for energy consumption and CO_2 emissions exhibit regional differences, but the differences are not very obvious.

(6) Household income affects indirect energy consumption and CO_2 emissions, with higher levels for high-income compared to low-income households. The higher the income, the more diverse is the energy consumption and CO_2 emission structure.

Based on the study results, we propose the following policy implications.

(1) The government should improve thermal and power facilities to enhance heating facilities and avoid energy loss during production and transportation. Considering the large power consumption for air conditioning, a standard for indoor temperatures should be set. Energy-efficient consumption of home appliances should be promoted to reduce energy consumption and CO_2 emissions.

(2) Citizens should be encouraged not to pursue an extravagant lifestyle. Energy-conserving cultural entertainment should be promoted. Goods wastage should be avoided and high-energy sectors such as paper-related industries should be controlled to reduce energy consumption and CO_2 emissions.

(3) The efficiency of coal use in rural areas should be improved. Rural households need to develop a variety of energy resources and to make full use of biomass energy and biogas to avoid a single-energy structure and low efficiency.

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