Rural Energy Consumption and its impacts on Climate Change

      

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Content

Executive Summary

With support from the Blue Moon Fund (BMF), Global Environmental Institute (GEI) started this research to gain an understanding of energy consumption in rural China, the impacts of rural energy consumption on climate change, and analyzing factors affecting energy consumption and CO_2 emissions.

Refers to energy consumption, this report mainly analyze the current situation, development pattern and future trends of rural residential and production energy consumption, with more focus on residential sector. It finds out that rural residential energy consumption in China shows obvious structure transitions from non-commercial energy to commercial energy，which indicates that more CO_2 emissions will be generated from rural energy sector. The use of residential commercial energy is increasing fast since 2001, with average annual per capita growth rate of 10%, nearly 1.5 times faster than that of urban. As for rural production energy consumption, the total energy consumption and structure of different commercial energies have been keeping stable.

As for rural energy on climate change, this report analyzes the CO_2 emissions generated from rural residential sector. It finds out that the major contributor to CO_2 emissions from rural residential sector is coal and electricity (in direct emissions generated from thermal power generation), followed by LPG. However, there is a significant difference in southern and northern rural areas because of climate difference. In southern rural areas, the biggest contributor is electricity, followed by coal and LPG; while in northern rural areas, the biggest contributor is coal, mainly for space heating in winter, followed by electricity.

As for factors affecting energy consumption and CO_2 emissions, it finds out that the key factor is rural income level based on relevance analysis. Huge fossil fuel consumption will cause huge CO_2 emissions, and huge demands, whether for heating or cooking or both, together with the increasing ability to pay because of improvement of rural people's livelihood, will cause huge fossil fuel consumption. The CO_2 emissions generated from rural residential sector will keep increasing in the business as usual scenario. When rural per capita income reaches about 8489 Yuan/year in 2020 （predicted according to current growth rate）, rural China will need to consume 111, 68 PJ electricity and 3,258 PJ LPG, the rural per capita CO_2 emission will reach 0.59 ton, with the total rural residential CO_2 emission will reach 346,930,000 tons, under the shifting fossil fuel dominant energy consumption structure.

In order to cope with these serious challenges, several actions need to be taken. On national level, it is recommended to increase the proportion of renewable power generation, to reduce the proportion of thermal power generation. And also design and implement comprehensive policy on promoting renewable energy development. On household level, new ways of utilizing current available resources in rural areas like straw to produce cleaner, and more efficient renewable energy, e.g. biomass briquettes to replace coal, as well as promoting more other renewable energy sources to mitigate the huge demand on commercial energy and serious challenges

of CO_2 emissions from rural energy sector[1].

[1] GEI has finalized a technology report of suitable rural energy technologies and a test report of improved biomass stove technologies based on these research findings.

Acknowledgements

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1. Introduction

According to 2006 data from the International Energy Agency (IEA)，per capita emissions in Africa, Asia and Latin America, together home to a vast majority of the world's population and developing nations, remains below the worldwide average of 4.48 metric tons, especially in rural areas where per capita emissions are even lower(IEA, 2009). However, achieving economic growth and improvements in living standards in these regions requires an increase in energy consumption, and as a result, rural energy consumption structure is shifting steadily from traditional biomass-dominant to fossil fuel dominant. Energy consumption itself is growing rapidly, leading to significant growth in emissions from developing countries.

China is one such country experiencing rapid growth in rural energy consumption as a result of economic development and improving living standards, and thus faces a challenge in reducing rural emissions in the near future. Residential CO_2 emission is the third largest contributor to the overall CO_2 emission generated from energy activities(NDRC, 2004), according to the National Development and Reform Commission's (NDRC) 1994 data[2]. And rural CO_2 emission is growing faster than urban.

In this context, Global Environmental Institute (GEI) started a rural energy program, focusing on the effects of rural energy consumption on climate change, seeking out short to long-term solutions to rural energy consumption and emissions, along with selecting key technologies for demonstration and promotion. This report aims to gain an understanding of the type, efficiency, application and growth of rural energy use in China, and analyze the CO_2 emissions generated from rural energy consumption.

[1] This is currently the only comprehensive data available on CO_2 emissions in China.

2. Research areas, definitions and methodology

2.1 Research areas

This research mainly discusses the energy consumption situation in rural China from 2001 to 2008, the CO_2 emissions generated from rural energy consumption from 1996 to 2008, and the trends of rural energy consumption and CO_2 emissions until year 2020.

In terms of energy consumption, the major contents include the current status of rural energy consumption, e.g. types and quantity, the development of rural energy consumption from 2001 to 2008, e.g. quantity and structure, the analysis of reasons and affecting factors of the variations. Both residential and production energy consumption will be looked into, with more focus on rural residential consumption.

In terms of CO_2 emissions generated from rural energy consumption, only residential energy sector is focused on because of two reasons. Firstly, the total rural production energy consumption and the structure of different commercial energy fuels has been keeping stable for the past eight years; secondly, it is difficult to define the per capita CO_2 emissions generated from rural production energy sector because not all the goods produced in the rural production sector end up in the hands of rural residents, while most go to urban areas.

2.2 Definitions

Rural energy consumption refers to the final energy consumption by rural residents for residential needs and production activities in a given period of time, but excludes the consumption in conversion of primary energy into the secondary energy and the loss incurred through energy transformation(NSB, 2010). The rural energy consumption in this research includes both rural residential energy consumption and rural production energy consumption.

Rural residential energy consumption refers to rural residents' use of energy for cooking, heating, cooling, hot water, lighting, home appliances and other residential needs(CCICED, 2009). Rural production energy consumption refers to rural energy consumption used in the field of farming, forestry, animal husbandry, fishery & Water conservancy for production, transportation and manufacture, which doesn't include energy use of township and village enterprises (NSB, 2010).

In addition, this research uses the terms of commercial energy and non-commercial energy. Commercial energy refers to coal, electricity, oil, natural gas, coal gas and liquefied petroleum gas (LPG), mainly fossil fuels, while non-commercial energy refers to traditional biomass energy including firewood and straw, and other renewable energy including biogas, solar, small wind power and micro-hydro power, mainly non-fossil fuels.

2.3 Methodology

The main research methodology of this research is literature survey, including literature review and data analysis. Literature sources include reports and papers from knowledge database such as CNKI and Science Direct.

In most developing countries, data availability and authenticity of rural energy system is an inherent problem because data collection is mainly recalled-based (Malhotra, Rehman, & Bhandari, 2002). In China, without exception, the date related to rural energy consumption is collected and compiled by multi-sources and through different channels(Zhang, Yang, Chen, & Chen, 2009).

In this report, the major data resources for analyzing energy consumption and CO_2 emissions are *China Energy Statistical Yearbook* from National Statistics Bureau (hereinafter referred as NSB data), while data on non-commercial rural energy consumption is collected from *National Statistical Atlas of Rural Renewable Energy* from Chinese Ministry of Agriculture because it is not included in the NSB database (hereinafter referred as MOA data), which are the only available comprehensive and official source that covered most rural energy consumptions. The major data resource related to income and population is from China Statistics Yearbook.

As far as the rural production energy consumption, data comes from NSB which only contains commercial fuels. Though data from MOA includes non-commercial energy for rural production, it only lists firewood and the statistics criteria are different from that of NSB.

3. Rural Energy Consumption in China

This section explores the variance of total and per capita rural energy consumption as well as its structure change from 2001 to 2008. In 2008, the total rural energy consumption in China was 11017.39 PJ (PJ=10^{15} Joule), with rural residential energy consumption accounting for 9803.23 PJ, and rural production energy consumption 1214.16 PJ.

3.1 Rural residential energy consumption in China

In 2008, the total rural residential energy consumption is 9803.23 PJ and the per capita rural residential energy consumption is 13590.12 MJ (MJ=10^{6} Joule). Non-commercial energies constitute the major parts, with traditional biomass (straw and firewood) accounting for 70% and other renewable energy (including biogas, solar, etc) 4%. The percentage of commercial energy is around 26%, of which coal accounts for 59% and electricity 27%.

3.1.1 General situation of rural residential energy consumption

Based on the available data, the basic finding is that total rural residential energy consumption has increased from 8201.03 PJ in 2001 to 9803.23 PJ in 2008，with an average annual growth rate of 3%. Correspondingly, the per capita energy consumption has increased at a rate of 4% from 10307.59 MJ in 2001 to 13590.12 MJ in 2008. As is shown in Figure 1, the total rural residential energy consumption in China illustrates a trend of slow increase. However, the consumption of commercial energy is growing very fast, while the use of biomass even began to decrease since 2006, which will be further explained in the following sections.

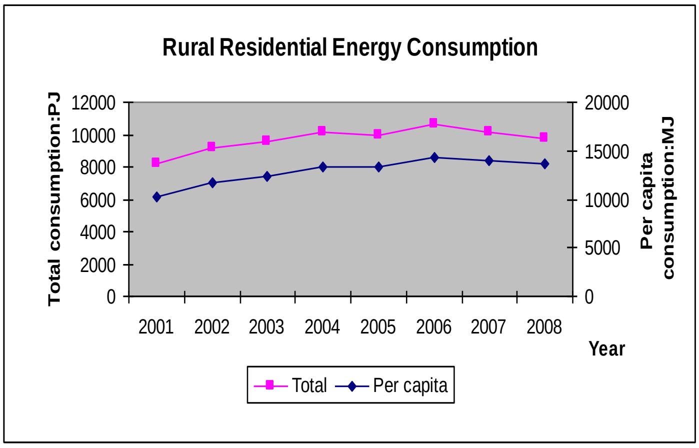


Figure 1: Total and per capita rural residential energy consumption in rural China, 2001-2008

A close examination of the main components shows that the structure of rural residential energy consumption has some transition from traditional energy use mode to a more commercial energy use mode throughout the years of study. As is shown in Figure 2, the most obvious trend is the decreased proportion of traditional biomass use and increased percentage of commercial energy and renewable energy.

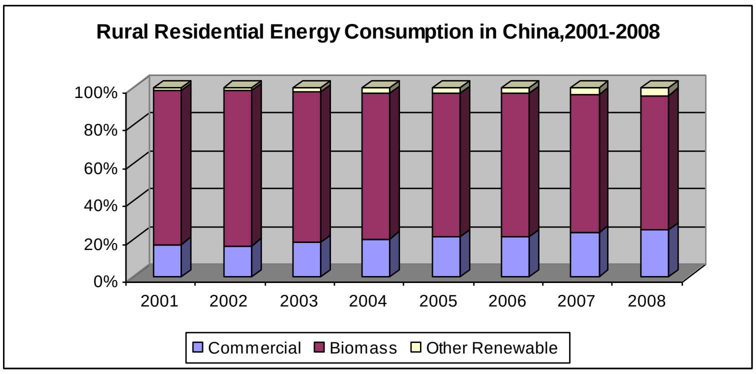
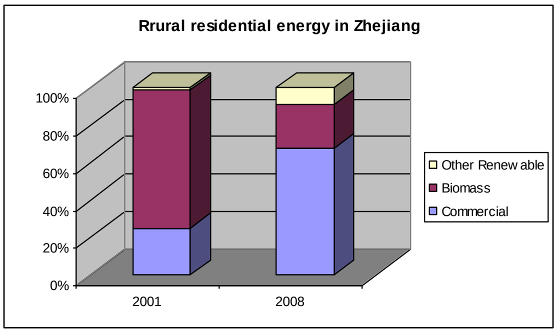


Figure 2: Percentages of commercial, biomass and renewable energy，2001 -2008

In 2001, of the rural residential energy consumption, commercial energy accounted for 17.13%, biomass 81.51% and other renewable energy only 1.35%, but the structure changed to commercial energy 25.09%, biomass 70.91% and other renewable energy 4.01%，as described in figure 2. The average annual growth rates for commercial and other renewable energy from 2001 to 2008 are 8.33% and 19.78% respectively, while that of traditional biomass was only 0.56%.



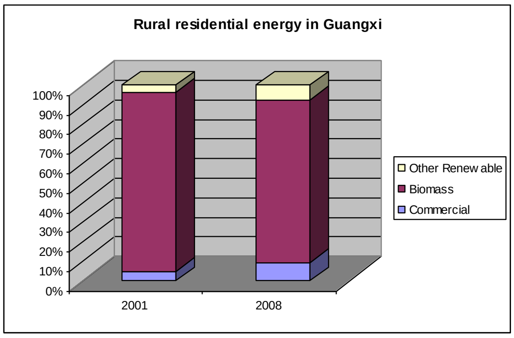


Figure 3: Change of rural residential energy structure in Zhejiang and Guangxi, 2001-2008

At provincial level, the change of rural residential energy consumption reflects similar patterns, in both developed and developing provinces. Take Zhejiang and Guangxi as an example[3]. Zhejiang is located at eastern coast of China with per capita annual income of rural residents as 4582Yuan in 2001 and 9258 Yuan in 2008, while Guangxi is located in the southwestern part of China, with per capita annual income of rural residents as 1944 Yuan in 2001 and 3690 Yuan in 2008. The annual income of rural residents in China was 2366 Yuan and 4761 Yuan in 2001 and 2008 respectively.

As is shown in Figure3, from 2001 to 2008, the percentage of commercial energy of rural residential energy consumptions has increased from 24.99% to 67.41% in Zhejiang, and increased from 4.61% to 9.23% in Guangxi. Meanwhile, the percentage of biomass energy of rural residential energy consumptions has decreased from 73.91% to 23.57% in Zhejiang, and decreased from 91.89% to 83.32% in Guangxi. Thus it affirms that the structure of rural residential energy consumption has changed from traditional energy use mode to a more commercial energy use mode, no matter in developed or developing provinces. This also indicates that commercial energy (mainly fossil fuels emitting CO_2) and other renewable energy will replace the traditional used biomass with the development of economy.

[3] The annual income of rural residents in China was 2366 Yuan and 4761 Yuan in 2001 and 2008 respectively, therefore Zhenjiang and Guangxi are considered as developed and developing areas separately in this report.

As Figure3 indicates, in 2001 the use of biomass energy was dominant in rural residential energy consumption in both Zhejiang and Guangxi provinces. However, in 2008, the developed province, Zhejiang has switched to commercial energy dominant, while the developing province, Guangxi is still biomass energy dominant.

3.1.2 Residential commercial energy consumption

Total rural residential commercial energy consumption has increased substantially from 1405.22 PJ in 2001 to 2459.6 PJ in 2008，almost twofold with an average annual growth rate of 8%, as the figure 4 indicates.

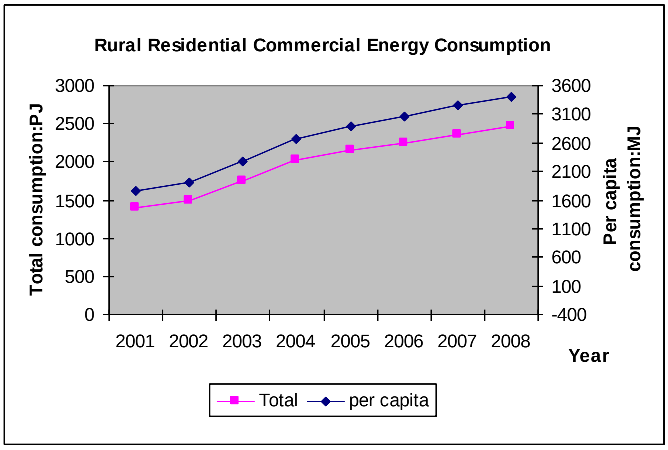


Figure 4: Total and per capita rural commercial residential energy consumption, 2001-2008

Correspondingly, the per capita energy consumption has increased at a faster rate of 10% from 1766.17 MJ in 2001 to 3409.72 MJ in 2008. The total and per capita rural residential commercial energy use in rural China illustrates a trend of rapid increase throughout the years of study.

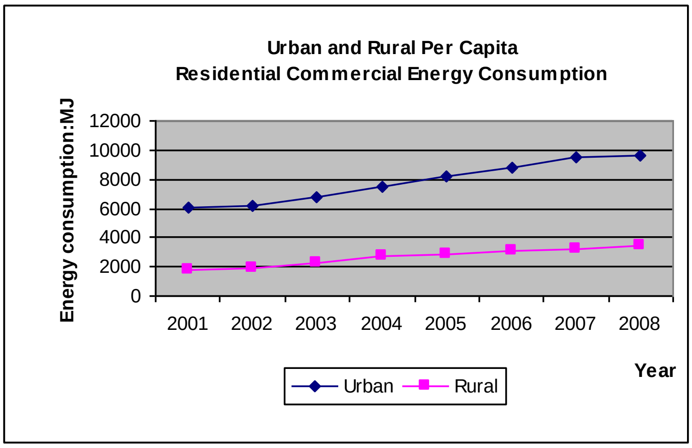


Figure 5: Rural and Urban per capita residential energy consumption in China, 2001 to 2008

Moreover, rural per capita residential commercial energy consumption is increasing at a rate much faster than that of urban citizen. As is shown in Figure 5, the average annual growth rate of urban residential energy consumption from 2001 to 2008 was 7%, while that of rural residential energy consumption was nearly 1.5 times faster. However, it should be noticed that even in 2008, urban per capita residential commercial energy consumption was 9565.45 MJ, which was almost 3 times more than rural farmer, indicating the huge potential use of commercial energy in rural areas in the future.

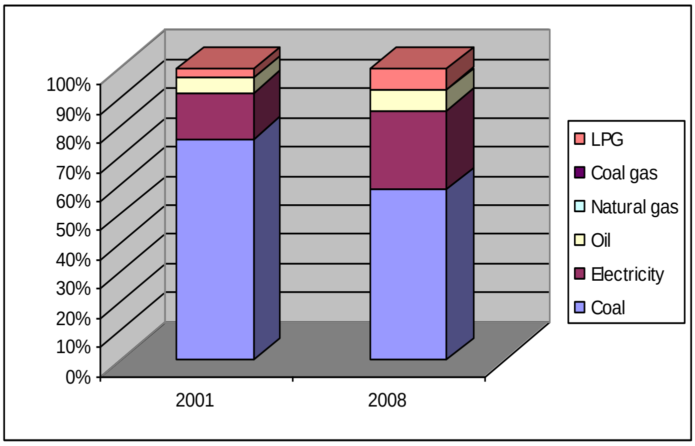


Figure 6: Comparison of rural residential commercial energy consumption structure in 2001 and 2008

In the mix of commercial energy, as is shown in Figure 6, coal has been the main source throughout years of study, accounting for 58.69% in 2008, since China is a country rich in coal resources. Meanwhile, the use of electricity, oil and LPG has increased fast in rural residential areas. The average annual growth rate for LPG, electricity and oil are 21.67% 16.99%, and 13.34% respectively from 2001 to 2008.

As a cleaner energy form with high quality and more convenience than coal, LPG, which is liquefied in a small steel container, has experienced a high growth rate of 21.67% from 2001 to 2008. With the mature market and increasing income of rural farmers, it is expected that the consumption of LPG in rural China will continue the rapid growth.

The rapid increase of the electricity consumption is mainly due to the development of rural electrification through building electrical network and small hydro plants since the 1980s(Zhang, et al., 2009). Many rural families now can afford home appliances such as washing machine, color TV etc, and even high energy consumption such as refrigerators and air conditioners can be found among wealthy rural families(Wang XH & Feng ZM, 2001).

3.1.3 Residential non-commercial energy consumption

Residential Biomass Energy Consumption

As Figure 7 shows, biomass energy consumption including firewood and straw increased at a very low rate from 2001 to 2006, reaching the peak at 8042.49 PJ in 2006.During 2006 to 2008, biomass energy consumption declines gradually, which is in contrast to the fast growth of commercial energy consumption in rural areas. In specific, straw use is increasing at a low average rate of 2%, which firewood use is decreasing at an average rate of 2%.

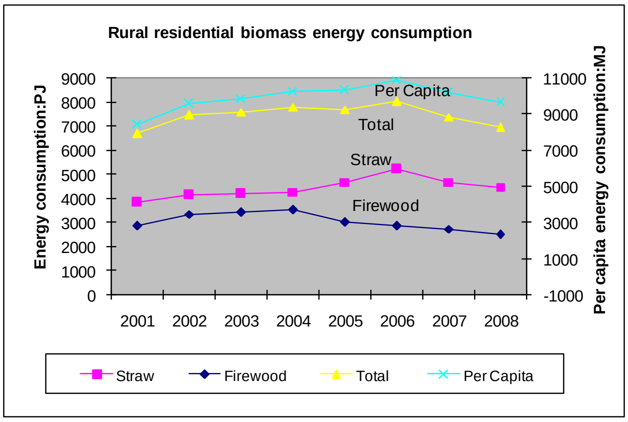


Figure 7: Total and per capita rural residential biomass energy consumption, 2001-2008

This may be attributed to income growth in rural areas, and thus the ability to afford more convenient and cleaner commercial energy on the market. Nevertheless it should be noted that in 2008 biomass energy consumption accounted for 70% of total rural residential energy consumption. Most biomass fuels are mainly used for cooking and heating by direct combustion with low efficiency, for instance, the conversion efficiency is only 10-20% of domestic cooking stoves(Zhang, et al., 2009). With the increasing income of rural farmers, it can be expected the use of traditional biomass energy will keep on decreasing. The possible solution to replace fossil fuel with biomass is to turn biomass energy into high quality commercial energy, such as biomass briquette.

Residential Other Renewable Energy consumption

As Figure 8 indicates, other renewable energy consumption as a whole has increased very fast over the 2001-2008 period, with an average annual growth rate of 19.78% and reached 392.63 PJ in 2008. Correspondingly, the average annual per capital growth rate of residential other renewable energy consumption is 21.47%.

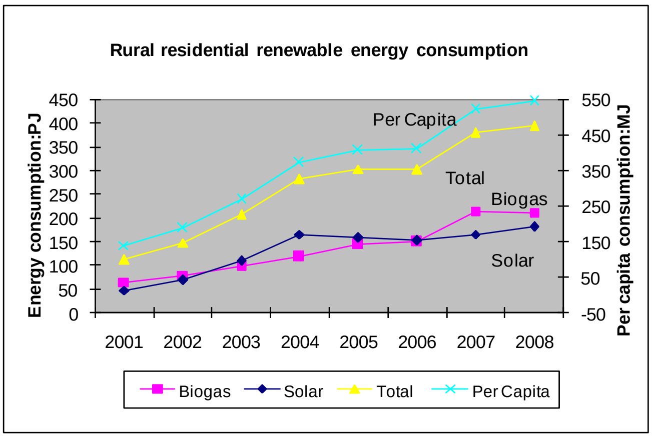


Figure 8: Total and per Capita rural residential renewable energy consumption

Particularly the total consumption of biogas and solar energy has experienced rapid average annual growth rates of 18.47% and 21.45% respectively. In addition, small wind and micro hydro power use have also shown steady increases. The particularly high growth in solar energy may stem from rural residents' increasing income level and the maturity of solar water heating technology and markets. Meanwhile, the Chinese government, along with civil society, has made consistent efforts to promote biogas use in rural areas, which has clear advantages in terms of waste management and saving energy costs vis-à-vis fossil fuels. In 2006, *Renewable Energy Law* was issued, which will further promote the development of renewable energy such as biogas, biomass briquette, wind and solar energy. However, it is argued that more policy and incentive measures are needed and market mechanism should be improved to advance the utilization of renewable energy(NDRC, 2007).

3.2 Rural production energy consumption

As is shown in Figure 9, the energy consumption for rural production has increased from 765.36 PJ in 2001 to 1214.16 PJ in 2008, which is used in the field of farming, forestry, animal husbandry, fishery and water conservancy for production, transportation and manufacture. Correspondingly, per capita energy consumption for rural production has grown from 961.65 MJ in 2001 to 1683.18 MJ in 2008.

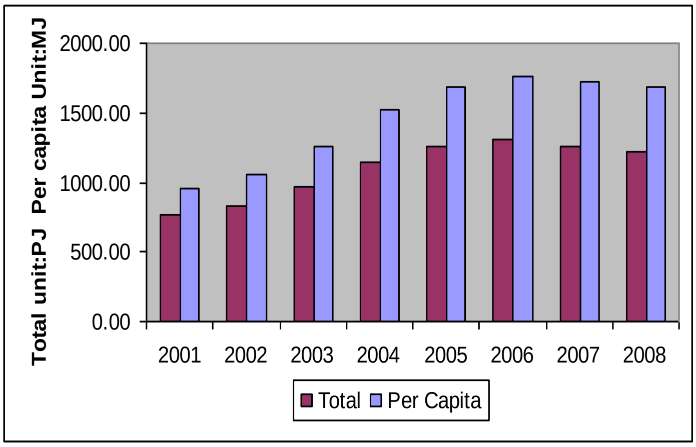


Figure 9: Total and Per capita rural production energy consumption, 2001-2008

The major parts of commercial energy for rural production are coal, oil and electricity, which constitute 98.6% of the total energy consumption in total in 2008. Figure 10 describes the structure change of rural production energy consumption; the percentage of different commercial energy fuels keeps stable from 2001 to 2008, with coal accounting for 27.9%, oil 44.4% and electricity 26.3% in 2008.

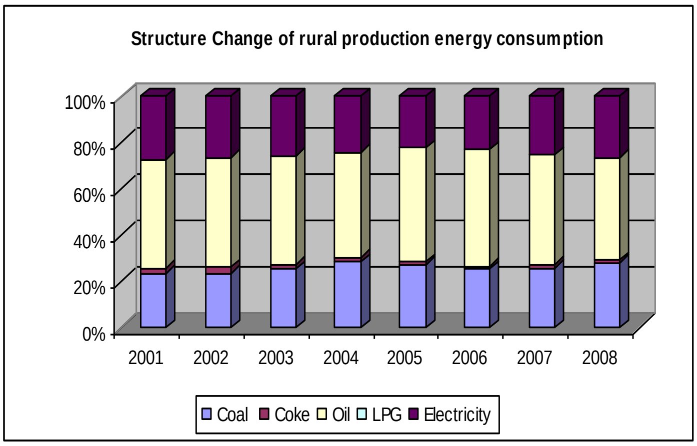


Figure 10: Structure change of rural production energy consumption, 2001-2008

3.3 Summary

Based on the analysis of available statistics data from 2001 to 2008, we can see that rural residential energy consumption in China shows obvious transitions from non-commercial energy to commercial energy. The use of residential commercial energy is increasing fast during the years of study, with average annual per capita growth rate of 10%, nearly 1.5 times faster than that of urban. On the other hand, biomass energy consumption increased at a very low rate in total, while firewood use is decreasing at an average rate of 2%. Due to strong government policy support, all other renewable energy consumption as a whole has increased very fast over the 2001-2008 period with average annual growth rate of 19.78%. However, it should be noticed that in 2008 biomass energy consumption accounted for 70% of total rural residential energy consumption, indicating huge potential increasing use of commercial energy in rural China if no measures were taken.

As for rural production energy consumption, it mainly uses commercial energy for production, transportation and manufacture in the field of farming, forestry, animal husbandry, fishery and water conservancy. The major commercial energy fuels are coal, oil and electricity, accounting 98.6% of the total energy consumption in 2008. Though the total energy consumption has increased steadily from 2001 to 2008, the structure of different commercial energy fuels keeps stable.

4. Emissions generated from rural residential energy consumption in China

4.1 Methodology

In light of non-fossil fuel consumption is considered carbon neutral, their GHG emissions are calculated to be zero, including both traditional biomass fuels and renewable fuels. Therefore, the GHG emission in this report only refers to emissions generated from fossil fuels). Since CO_2 is the major gas influencing climate change, this report will not focus on analyzing CO, CH_4 and other GHG gases' emissions generated from fossil fuel consumption, but CO_2.

2006 IPCC Guidelines for National Greenhouse Gas Inventories presents three tiers for estimating CO_2 emissions from fossil fuel combustion. According to the situation in China, Tier 1 is applied for this report. Tier 1 is a fuel-based method, in which CO_2 emissions are estimated based on the total amount of fuel combusted and default emission factors(IPCC, 2006), shown as below.

CO_2 emissions (kg) = Default Emission Factor (KGCO_2/TJ)*Total Fuel Consumption (kg)* Calorific Value (KJ/kg)

Where:

- Default emission factor is from '*default emission factors for stationary combustion in the residential and agriculture/forestry/fishing/fishing farms categories*' according to 2006 IPCC Guidelines. For conservative estimation, the lower default emission factor is applied for this research;
- Total fuel consumption is from *China Energy Statistical Yearbook 2009*; and
- Calorific value is from *China Energy Statistical Yearbook 2009* and the average low Calorific value is applied for this report.

For rural and urban residential energy sector, the main categories of fossil fuels are Raw Coal, Other Washed Coal, and Briquettes, Gasoline, Kerosene, and Diesel, Liquefied Petroleum Gas, Natural Gas, Electricity, Coke and Coal Gas, based on China Energy Statistical Yearbook. The emission of all these fossil fuels can be calculated simply by the formula before, except for Electricity.

Electricity is generated mainly from thermal power, hydropower, and nuclear power separately. The CO_2 emissions generated from electricity is relevant to the percentage of thermal power generation and coal input for thermal power generation in the year, which changes every year. The calculation formula of Electricity is as below.

CO_2 emissions = Total Electricity Consumption* percentage of thermal power generation* coal input for thermal power generation in the year* Default Emission Factor of coal * Calorific Value of coal

Where:

- Total electricity consumption and calorific value of coal are based on *China Energy Statistic Yearbook 2009*;
- Default emissions factor of cola is from '*default emission factors for stationary combustion in the energy industries*' according to 2006 IPCC Guidelines ; and
- Percentage of thermal power generation and coal input for thermal power generation are based on *China Power Yearbook 2009.*

The emission factor and low Calorific Value of all these fossil fuels, percentage of thermal power generation and coal input for its generation are shown in table 1 and 2 separately.

Table 1: Emission factor and low Calorific Value of different fossil fuels

Fuel Type	Low Calorific Value	Default Emission Factor
Raw Coal	20,908 KJ/kg	87,300[4] kg/TJ
Other Washed Coal	8,363 KJ/kg[5]	87,300 kg/TJ
Briquettes	20,908 KJ/kg[6]	87,300 kg/TJ
Coke	28,435 KJ/kg	95,700 kg/TJ
Other Coal Gas	5,2277 KJ/m^3	37,300 kg/TJ
Gasoline	43,070 KJ/kg	72,600 kg/TJ
Kerosene	43,070 KJ/kg	70,800 kg/TJ
Diesel	42,652 KJ/kg	72,600 kg/TJ
Liquefied Petroleum Gas	50,179 KJ/kg	61,600 kg/TJ
Natural Gas	38,931 KJ/m^3	54,300 kg/TJ

Table 2: Percentage of thermal power generation and coal input

Year	Percentage of thermal power generation (%)	Coal input for thermal power generation（g/KWH）

[4] The default emission factors of Raw Coal, Other Washed Coal, Briquettes, and Other Coal Gas are not available from 2006 IPCC Guidelines, for the concepts are not used in the Guidelines. For conservative estimation and the definition of these fuels, the lowest emission factor of different kinds of coals, 87,300, and the lowest emission factor of derived gases, 37,300, is applied for this report.

[5] Two data is presented in China Energy Yearbook. For conservative estimation, the lower one is applied for this research.

[6] No Calorific Value data is available for briquettes. According to the definition of briquettes, the calorific value of raw coal is applied to estimate briquettes' CO_2 emissions.

[7] There are six kinds of other gases presented in China Energy Yearbook with six different data for Calorific Value. For conservative estimation, the lowest is applied for this research.

1996	81.4	377
1997	81.6	375
1998	81.1	373
1999	81.5	369
2000	81.0	363
2001	81.2	357
2002	81.7	356
2003	82.9	355
2004	82.5	349
2005	81.8	343
2006	83.3	342
2007	83.3	332
2008	81.2	322

4.2 CO_2 emissions generated from rural residential sector, 1996-2008

Based on the formula before, this part looks into the situation of CO_2 emissions generated from rural residential sector from 1996 to 2008, its structure change, and the differences between CO_2 emissions generated from rural and urban residential sectors. Emissions from all the fossil fuels are calculated separately, while integrated into six types when being analyzed, which are Coal (including Raw Coal, Other Washed Coal, and Briquettes), Oil (including Gasoline, Kerosene, and Diesel), Liquefied Petroleum Gas, Natural Gas, Electricity, and Others (Coke and Coal Gas) .

4.2.1 CO_2 emissions generated from rural residential sector

The change of rural energy consumption has leading to significant change of CO_2 emissions generated from rural residential sector. According to figure 11, it is clear that the overall CO_2 emissions generated from rural residential sector has increased from 147 million tons to 284 million tons from 1996 to 2008, with an average annual growth rate of 6.14%. The per capita CO_2 emission has increased from 0.17 ton/person to 0.39 ton/person since 1996, with an average annual growth rate of 12.69 %. If we look into the CO_2 emissions per energy consumption, it has increased from 0.013 t/J to 0.021 t/J from 2001 to 2008.

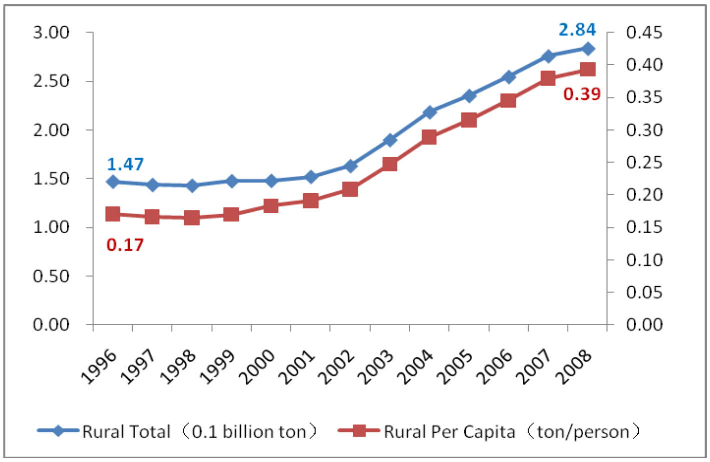


Figure 10: CO_2 emissions generated from rural residential sector, 1996-2008

Moreover, according to the data in figure 12, it is obvious that per capita CO_2 emissions generated from rural sector has been keeping increasing since 1996 while it is actually volatile in urban sector, decreased significantly from year 1999 to 2000, then increased slowly from 2000 to 2008. In total, the per capita CO_2 emissions generated from urban residential sector has increased from 0.48 ton/person to 0.56 ton/person, with a low average annual growth rate of 2.31%, while the average annual growth rate in rural sector is 12.69 %. This indicates that fossil fuel consumption by rural people is increasing at a significant fast speed.

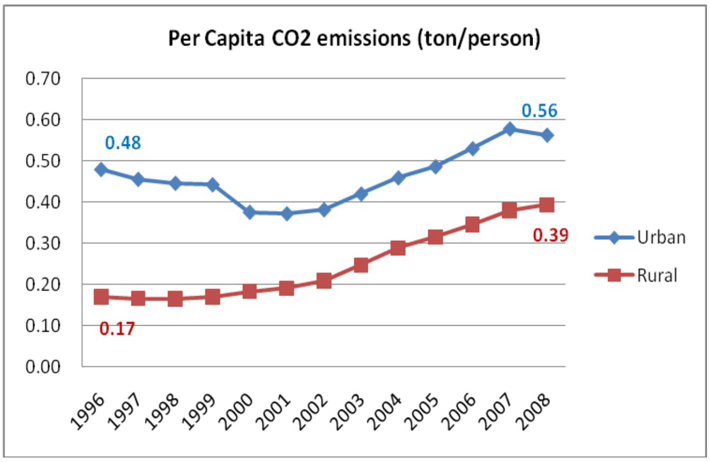


Figure 12: Per capita CO_2 emissions generated from rural and urban sector

The analysis above is the national overall situation of rural residential CO_2 emissions from 1996 to 2008. On the provincial level, we can see the top 2 CO_2 emitters of rural China in 2008 are rural Beijing (1.95 ton/person) and rural Shanghai (1.29 ton/person), if we look into the per capita CO_2 emissions. When we look into the overall CO_2 emissions, Hebei (210 million tons) is the biggest emitter, followed by Guangdong and Henan (200 million tons).

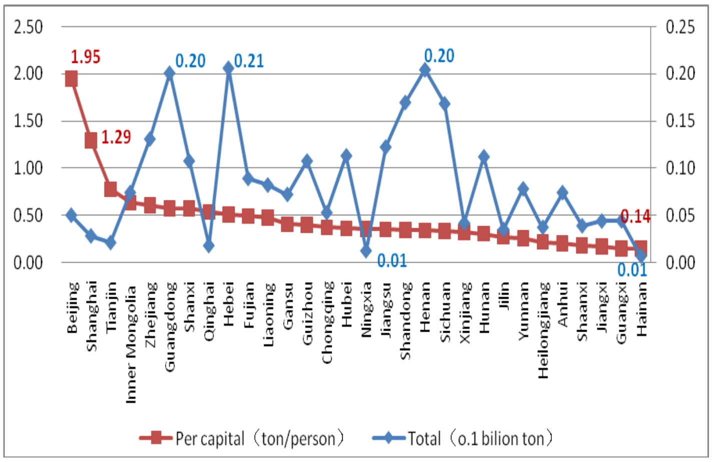


Figure 13: Per capita and total CO_2 emissions in rural residential sector in 2008

Current research points out that the income level is a major factor determining the households' energy consumption (Fan & Xu, 2006; Wang & Song;1993 Cheng & Chen, 2004; Wang et al., 1998), which will further impact emissions generated from different energy sources. In order to analyze the relevance between per capita CO_2 emissions and per capita income more deeply, a XY Scatter Diagram of the 30 provinces and cities is done, from which we can see that the income affects CO_2 emissions significantly and positively, the per capita income has 71.7% influence on per capita emissions, see Figure 14.

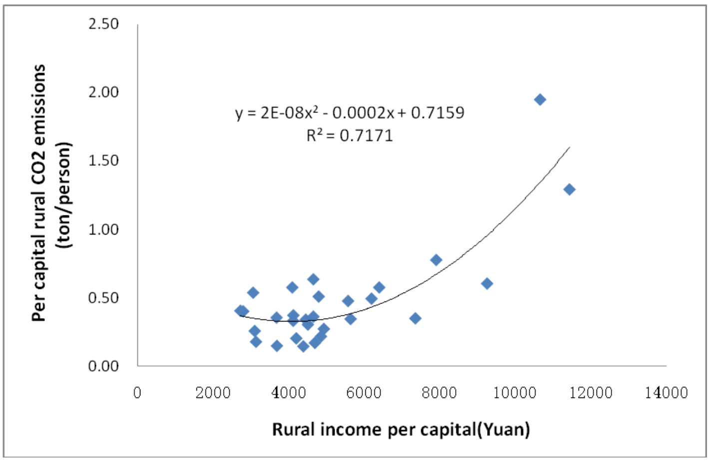


Figure 14: Scatter Diagram of per capita income and CO_2 emissions in rural China in 2008

As rural Beijing and rural Shanghai are the two richest rural areas in China, the energy consumption pattern in these two areas presents a very typical development direction of other rural areas, along with economy growth and urbanization, which means that more and more coal, electricity, and LPG will be used for heating, lighting, cooking etc, leading to more CO_2 emissions generated from rural residential sector.

4.2.2 Structure of CO_2 emissions from rural residential sector

Figure 15 indicates that coal and electricity are the major contributors to CO_2 emissions, accounting for more than 90% since 1996, followed by LPG and Oil. Although LPG is still not the major contributor, its percentage has increased from 1% to 4% since 1996, with an average annual growth rate of 15.55%, which has become the one of the major contributors to CO_2 emissions in rural residential sector.

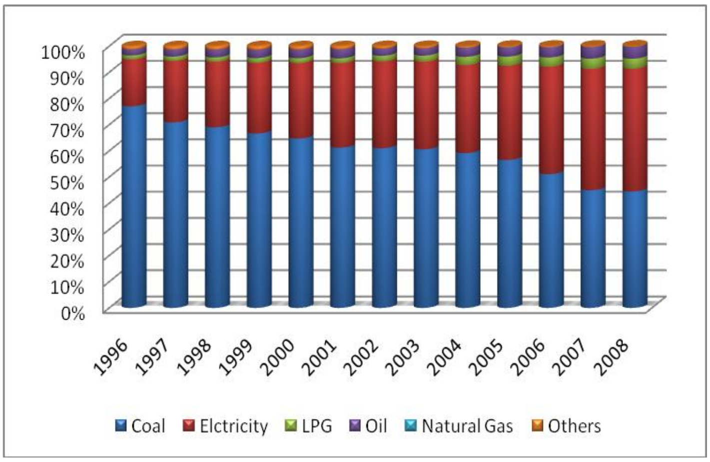


Figure 15:CO_2 emissions generated from rural residential sector, 1996-2008

However, electricity has become the biggest contributor to CO_2 emissions, accounting for 47% in year 2008, compared to coal accounting for 44%. As mentioned in part 4.1, emissions generated from electricity are mainly related to coal used for power generation, therefore, the conclusion is that the major contributor to CO_2 emissions in rural residential sector is coal burning activities (91%), including household consumption and power generation.

As discussed in 4.2.1, rural Beijing and Shanghai are the biggest two emitters per capita and Hebei and Guangdong and Henan are the biggest three emitters in total in 2008. As figure 16 indicates, the major contributors to CO_2 emissions in these provinces and cities are also coal, electricity and LPG separately, although the proportion is different. For example, in rural Beijing, emissions generated from coal consumption accounts for about 64%, followed by electricity (31%). In rural Henan and Hebei, emissions generated from coal and electricity account for more than 95% of the total emissions. However, the situation in rural Guangdong and Shanghai is different with other places, e.g. the biggest contributor in rural Shanghai is Oil, followed by electricity and LPG, while coal only accounts for less than 10%. The possible reason for this difference is related to the climate difference, because both Guangdong and Shanghai are in southern China while the other three are in northern China. This climate difference further leads to different energy demands in northern and southern China, e.g. people in northern part have a greater demands for coal to satisfy their heating demands in winter.

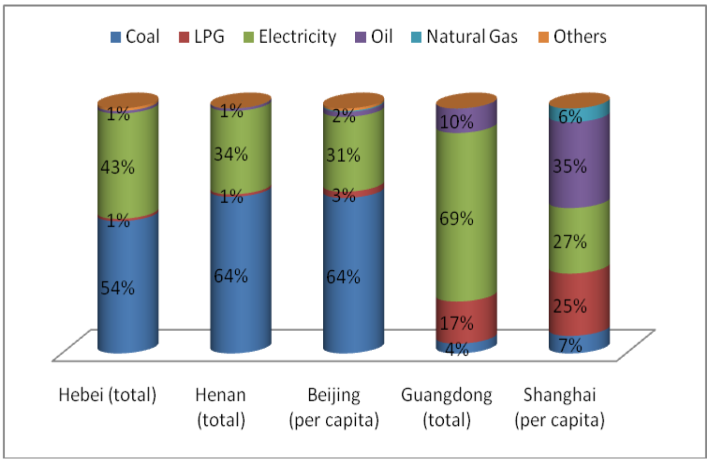


Figure16: CO_2 emissions in rural Beijing, Shanghai, Hebei, Henan and Guangdong in 2008

In order to further analyze and explain the structure difference in these five provinces, the structure of southern and northern China[8] is discussed, because there is a huge difference in energy demands for heating in southern and northern China.

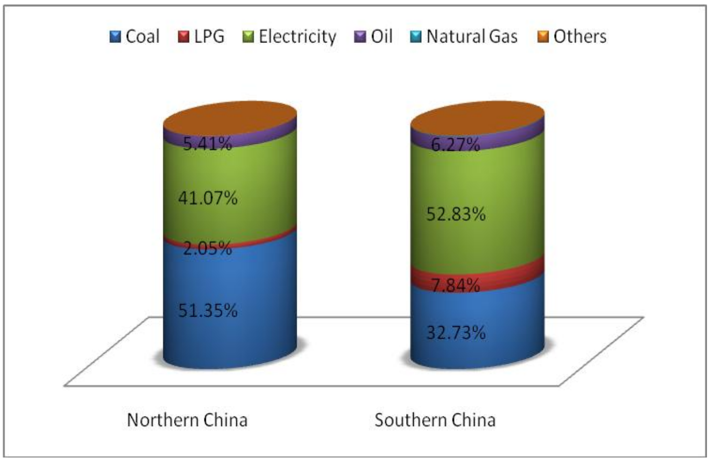


Figure 17: CO_2 emissions structure in Northern and Southern rural China, 2008

The result from figure proves the hypothesis to some extent that the structure is different in southern and northern China because of the climate difference, which

[8] Southern China includes Jiangsu, Zhejiang, Shanghai, Hubei, Hunan, Sichuan, Chongqing, Guizhou, Yunnan, Guangxi, Jiangxi, Fujian, Guangdong, Hainan, and Tibet; Northern China includes Beijing, Tianjin, Xinjiang, Hebei, Gansu, Shanxi, Shaanxi, Qinghai, Shandong, Henan, Anhui, Liaoning, Jilin, Heilongjiang, and Inner Mongolia.

leading to different energy demands by local people. Specifically, in northern China, the biggest contributor to CO_2 emissions is coal (51%), followed by electricity (41%), while in southern China, the biggest contributor is electricity (53%), followed by coal (33%) and LPG (8%).

4.3 Summary

From the research and analysis above we can see that rural residential CO_2 emission is keeping increasing at a much faster rate than urban areas, although the per capita CO_2 emissions generated from rural sector is still lower than urban areas.

The major contributor to CO_2 emissions from rural residential sector is coal and electricity, followed by LPG. However, there is a significant difference in southern and northern rural areas because of climate difference. In southern rural areas, the biggest contributor is electricity, followed by coal and LPG; while in northern rural areas, the biggest contributor is coal, followed by electricity.

Huge fossil fuel consumption will cause huge CO_2 emissions, and huge demands, whether for heating or cooking or both, together with the increasing ability to pay because of improvement of rural people's livelihood, will cause huge fossil fuel consumption. The CO_2 emissions generated from rural residential sector will keep increasing in the business as usual scenario. In order to slow or reduce CO_2 emissions generated from rural residential sector, new low-carbon technologies need to be developed to replace coal for heating, cooking, and power generation.

5. The future trends of rural residential energy consumption and its emission

5.1 Main factors affecting residential energy consumption model

Factors affecting residential energy consumption can be described by using the conceptual framework called the "energy ladder"(Kirk R. Smith, Michael G. Apte, Ma Yuqing, Wathana Wongsekiarttirat, & Ashwini Kulkarni, 1993). As is shown in figure 18, with the economic development, people tend to move up the ladder and use cleaner, more efficient and more convenient fuels, replacing traditional biomass fuels and coal gradually(World Health Organization(WHO), 2006).

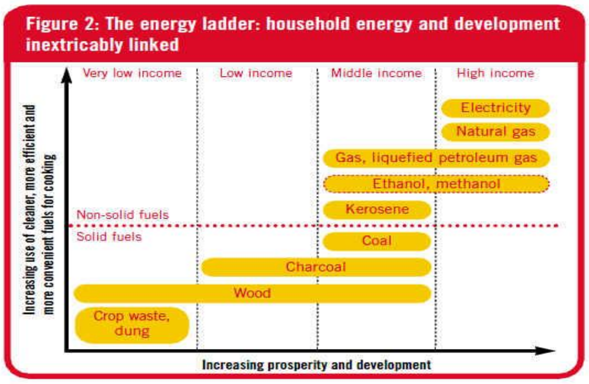


Figure 11: The energy ladder

Source:(World Health Organization(WHO), 2006)

In China, current researches also point out the income level is a major factor which determines the rural households' energy consumption (Fan & Xu, 2006; Wang & Song, 1993) . It is also found that the energy structure and the income level have close correlation. With higher income, farmers tend to use more commercial energy (Cheng & Chen, 2004; Wang et al., 1998)

5.2 Trend analysis on residential energy consumption

As discussed in chapter 3 and 4, rural per capita income is the key indicator affecting rural residential energy consumption and CO_2 emissions; therefore, the per capita income is analyzed before predicting the trends of rural residential energy consumption and CO_2 emission till 2020. We assume that the rural per capita income will keep increasing, and based on current rural per capita development rate from 2001 to 2008 and using Microsoft Excel's Linear regression function to predict the income level of rural areas from 2011 to 2020, see detailed results in table 3.

Table 3: Rural per capita income prediction

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Rural per capita income （Yuan）	5458	5794	6131	6468	6805	7142	7479	7816	8152	8489

To see more clearly about the relevance between rural per capita income and rural commercial energy (fossil fuel) consumption, we did a relevance analysis using Microsoft Excel and the result is below.

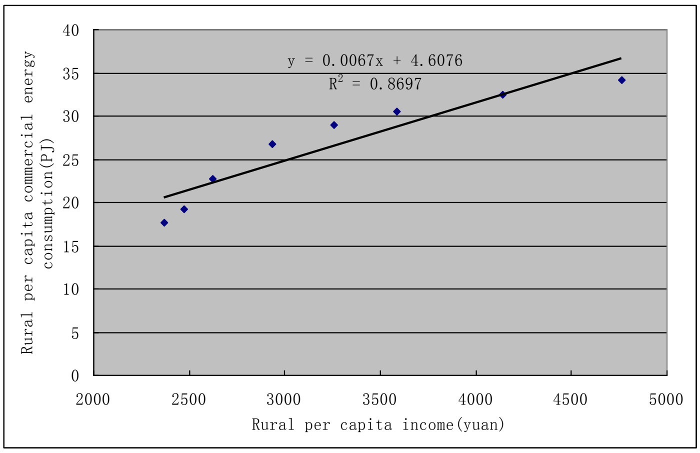


Figure 19: Relevance analysis on rural per capita income and rural per capita commercial energy consumption

Figure 20 indicates that rural per capita income does have a positive relevance as 86.97% with rural commercial consumption, under current shifting energy consumption structure. So, if we assume that the rural per capita income will keep increasing, we can see that rural commercial energy consumption will increase along with it.

As the former research indicates, electricity and LPG are preferred by rural residents among all the major source of rural residential commercial energy. So we can use the data of rural per capita income to predict the rural electricity and LPG consumption. First we also did the relevance analysis on rural per capita income and rural electricity consumption, see the results below.

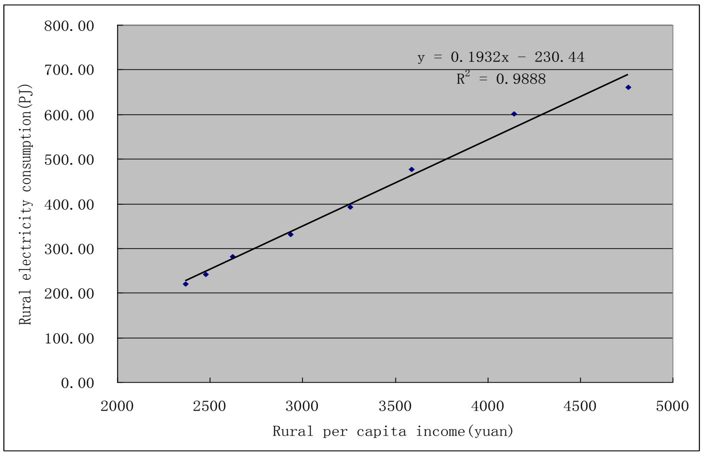


Figure20: Relevance analysis on rural per capita income and rural electricity consumption

We can see the rural per capita income has a strong relevance of 98.88% with rural electricity consumption, this means huge electricity demand in the coming ten years in rural areas, see detail result below:

Table 4: Rural electricity consumption prediction

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Rural per capita income（Yuan）	5458	5794	6131	6468	6805	7142	7479	7816	8152	8489
Rural electricity consumption(PJ)	824	889	954	1019	1084	1149	1214	1280	1345	1410

Similarly, we also did the relevance analysis on rural per capita income and rural LPG consumption, see the results below.

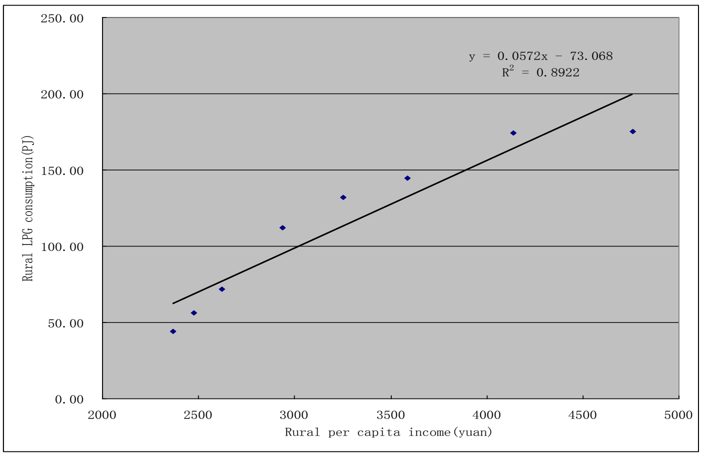


Figure 12: Relevance analysis on rural per capita income and rural LPG consumption

We can see the rural per capita income has a strong relevance of 89.22% with rural LPG consumption, this also means huge LPG demand in the coming ten years in rural areas, see detail result below.

Table 5: Rural LPG consumption prediction

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Rural per capita income（Yuan）	5458	5794	6131	6468	6805	7142	7479	7816	8152	8489
Rural LPG consumption (PJ)	239	258	278	297	316	335	355	374	393	413

From the above analysis we can see that from 2011 to 2020, rural China will consume 111, 68 PJ electricity and 3,258 PJ LPG. We should be aware that China has been a net importer of coal since 2007, and the overall available supply of LPG in 2008 is only 1,054PJ. This obviously poses a great challenge to the energy security; there would be not enough commercial energy to satisfy rural areas' huge energy demands.

5.3 Trend analysis on residential energy consumption emission

If we use the former analysis about rural per capita income, and to see its relevance with rural per capita CO_2 emission, we get the results below:

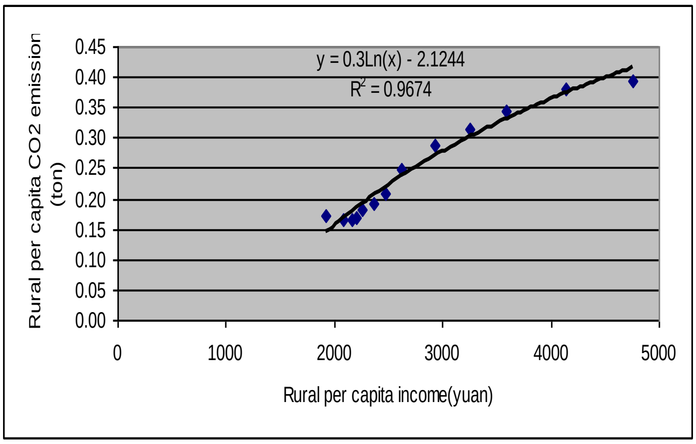


Figure 13: Relevance analysis on rural per capita income and rural per capita CO_2 emission

Based the analysis above, we can see the rural per capita income also have a strong relevance with rural per capita CO_2 emission. And we can also predict the rural per capita CO_2 emission and rural overall CO_2 emission using the formula above, the results are shown in table 6.

Table 6: Rural per capita CO2 emission and major commercial energy consumption prediction

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Rural per capita income（Yuan）	5458	5794	6131	6468	6805	7142	7479	7816	8152	8489
Rural per capita CO_2 emission(ton/person)	0.46	0.47	0.49	0.51	0.52	0.54	0.55	0.56	0.58	0.59
Rural total residential CO_2 emission(10^4ton)[9]	31298	32020	32636	33156	33590	33945	34227	34443	34597	34693

So, we can see from the table 6 that in the year 2020, when rural per capita income reach about 8489 Yuan, which is the income level of rural Beijing in 2006, the rural per capita CO_2 emission will reach 0.59 ton, with the total rural residential CO_2 emission will reach 346,930,000 tons, under the shifting fossil fuel dominant energy consumption structure. And if we use the Chinese government rural development goal, which means the rural per capita income will reach 9532 Yuan(CCCPC, 2008), and the rural per capita CO_2 emission will reach 0.62 ton, which means from 2010 to 2020, Rural China will emit 3,346,060,000 tons CO_2 by using current mostly coal fired power generation electricity and LPG according the predictions of electricity and LPG consumption data.

[9] Rural total CO_2 emission comes from rural per capita CO_2 emission plus rural population, rural population is calculated based the rural population linear regression variation rate from 200 to 2008.

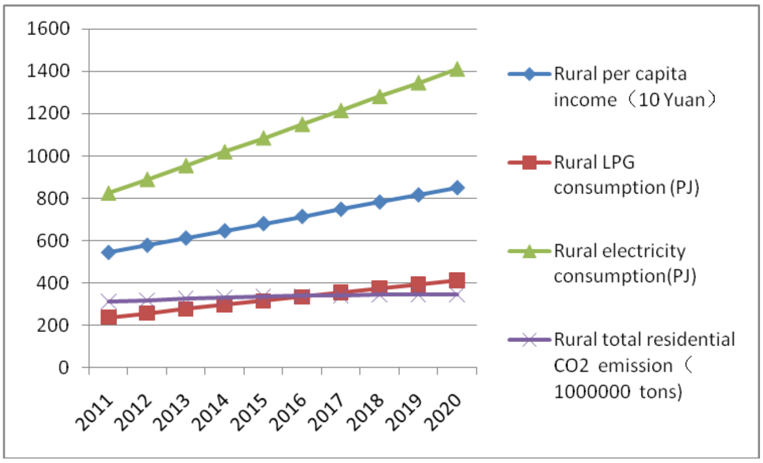


Figure 14: Rural CO_2 emission and major fossil fuel consumption projection

In the year 2020, rural China will reach the income level of rural Beijing 2006, as shown in the green line above. We can see that rural CO_2 emission and rural electricity and LPG consumption will keep increasing as well. That is the projected scenario if rural residential energy consumption pattern remains business as usual. Then if we want to reduce CO_2 emissions while keep the income increasing, we need to find a way to reduce leading fossil fuel like current mostly coal fired power generation electricity and LPG consumption.

5.4 Summary

From the analysis above we find that rural per capita income has strong relevance with rural residential CO_2 emissions, as well as rural electricity consumption and rural LPG consumption. It is assumed the rural per capita income will keep increasing, and based on this, we see huge electricity and LPG consumption in the coming decade. This will cause serious energy security crisis under the business as usual scenario. And also huge CO_2 emissions will come from rural residential sector, which will also have significant influence on realization of the nation's overall emission reduction targets

6. Conclusion and Recommendations

Based on the analysis of available statistics data, we can see that rural residential energy consumption in China shows obvious transitions from non-commercial energy to commercial energy. The percentage of biomass has dropped from 81.51% in 2001 to 70.91% in 2008, while ratio of commercial energy has increased from 17.13% to 25.09% during the same period. Moreover, the use of residential commercial energy is increasing fast, with average annual per capita growth rate of 10%, nearly 1.5 times faster than that of urban.

Correspondingly, total CO_2 emissions from rural residential energy consumption have significant increases from 147 million tons to 284 million tons from 1996 to 2008, with an average annual growth rate of 6.14%. The per capita CO_2 emission has increased from 0.17 ton/person to 0.39 ton/person since 1996, with an average annual growth rate of 12.69 %, almost 5 times faster than that of urban areas (growth rate in urban areas is 2.31%). There is a significant difference in southern and northern rural areas because of climate difference. In southern rural areas, the biggest contributor is electricity, followed by coal and LPG; while in northern rural areas, the biggest contributor is coal, followed by electricity.

Based on the conceptual framework of “energy ladder”, it is found the income of rural farmers is the main factor determining the consumption of the commercial energies. Therefore, if current fossil fuel dominant rural energy consumption structure goes on with the continuous increase of economy, it is for sure that China will face severe an energy crisis and much more greenhouse gas emissions generated from rural residential energy sector.

Generally, there are three approaches to reduce CO_2 emissions, that is reducing energy consumption, changing the energy structure and improving the energy efficiency(L.X. Zhang, C.B. Wang, Z.F. Yang, & Chen, 2010). In rural China, cutting down energy consumption was contradictory to the development of rural areas and the consumption of commercial energy is expected to increase along with the economic development according to the concept framework of "energy ladder". Therefore, to change the energy structure and improve the energy efficiency is the choices to satisfy the goals of both energy supply and CO_2 emission reduction in rural areas.

Since electricity and coal are the main sources for CO_2 emissions from rural residential energy consumption. It is recommended to increase the proportion of renewable power generation, such as small hydro power, wind power and solar PV, to reduce the proportion of coal fired power generation in rural areas at national level. At household level, it is recommended to replace coal fuels with modern biomass energy for cooking and heating, particularly for heating in Northern areas, e.g. improved biomass heating stove technology and biomass briquetting technology, because heating issue is a very significant challenge faced by rural people because of increasing price of coal fuels and increasing heating demands .

China has abundant biomass energy resources and there is around 700 million tons of straw produced each year, with 35% can be used as energy(Kou, Zhao, Hao, & Tian, 2008). Through modern technologies, traditional biomass can be converted into high grade energy similar to or even better than coal. Thus, modern biomass briquettes and pellets seem to be the first choice to replace coal and other commercial fossil fuels in rural areas, especially in northern areas. This will not only make full use of agricultural residues to produce clean energy, but also reduce CO_2 emissions at the same time. Based on the stove thermal efficiency and calorific value, 1.5 tons of biomass briquettes can replace 1 ton of coal fuels at household level. Therefore, around 160 million tons of coal fuels can be replaced if the 35% of straw can be briquetted, that means around 288 million tons of CO_2 emissions will be reduced annually.

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