Energy Consumption in Residential House and Emissions Inventory of GHGs, Air Pollutants in China

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Abstract

The energy consumption of residential housing in China was analyzed in detail by fuel type, urban and rural areas, province and partly by end-use type, based on China's energy statistics. In addition emissions of CO_2, SO_2 and NO_x were estimated from the energy consumption data in this study. The target period of provincial estimation is from 1995 to 1999. This is only the first step in providing a fundamental analysis, but this kind of primary study is very important to the basis of East Asian energy and environmental policy on climate change, regional and continental air quality, acidification, urban or social development and so on.

The most significant fuel in residential energy use in China is biomass in rural areas, which provided 65% of all fuel use in 1999. In total comprising, 42% from stalks(agricultural waste or crop residues), 22% firewood. In rural areas 80% of fuel use is biomass, 52% stalks and 28% firewood, but none in urban. Coal (including coal products) is dominant in urban areas at 44%, but in rural only comprises 15%, all areas averaging 22%. For residential energy this is far less than the 56% share of all primary energy consumption, including biomass.

Average annual energy use per capita in urban areas is 3.5GJ, in rural 11.7GJ, and for all areas 8.2GJ. Rural use is bigger than urban because of low efficiency biomass combustion for cooking and space heating. Per household use is: urban 10.9GJ; rural 51.9GJ; all areas 30.2GJ. Per capita average consumption in 1999 in China is 52% of the Japanese level in 1999, comparable to Japan in 1976. By provincial analysis, the north and inland regional areas have higher per capita and per household energy consumption levels, primarily due to the colder climate.

Estimated residential energy consumption including biomass and electricity is 10261PJ as low calorific value and secondary energy base in 1999, which is 28% of total consumption in China. CO_2 emissions amounted to 1010TgCO_2 (Including Biomass), SO_2 1950Gg and NOx 723Gg as NO_2.

Key words: energy-consumption; greenhouse-gas; air-pollutants; urban & rural; China

1. introduction

Residential household energy consumption, greenhouse gases and air pollutant emissions in China are analyzed based on the "China Energy Statistics Book (State Statistical Bureau, P. R. China (1998,2001))". From the view point of options for climate change strategy, residential energy consumption in China is very interesting. Emissions are high because of the large population size but heat demand requirements can vary significantly due to weather conditions, indoor thermal environmental level, residence type and life style of the region.

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Future trends of residential energy demand in China will be primarily affected by household type and facility efficiency, urbanization, and the expenditure level of households. In rural areas the majority of biomass fuel is composed of stalks (from agricultural waste), firewood. These are primarily used for cooking or space heating but used with low efficiency, therefore there is considerable remaining room for improvement. Biomass use in rural areas has decreased with the penetration of fossil fuels; however, an expansion of biomass use is expected as a potential greenhouse gas emission reduction option. This has been observed in urban areas with fuel switching from coal to city gas. The future trend of residential energy demand is one of the key factors of the climate change problem. However, there are also other problems to be considered, in particular poor indoor air quality caused by pollution from coal use in households. For these reasons, quantitative analysis of residential energy consumption in China is an important basis for research into climate change and air pollution.

2. Previous Studies

Our first trial analysis of China's energy consumption and air pollutant emissions was Tonooka Y.,S.Miura(1986). This paper created an SO_x emission inventory of East Asia by source (including residential), fuel type, country and province in China. This was revised many times with improved inventory methodologies and expanded to include NO_x, CO and NMVOCs. There are other similar emission inventory studies, for example Streets,D.G.,S.T.Waldhoff(2000). In that paper SO_2, NO_x and CO emissions in China are estimated, but energy consumption by sector was not reported. Biomass fuel use for cooking and space heating in rural residential houses was studied in Hall D.O.(1991) and looked at world biofuel consumption by countries, including China. A more recent study by Streets,D.G.,S.T.Waldhoff(1998), looks at Asian biofuel use as an emission source of acidification precursors and shows biofuel use in China by regions.

The most recent study of China (written in Chinese) focused on residential energy consumption from the view point of Greenhouse gas emission reduction. Hu X., K.Jiang(2001) studied China's recent trends in residential energy consumption in detail to 1995, for urban and rural areas. The results of our study are compared to theirs later on.

3. Estimation Methodology

3-1 Data Source

The national statistics of energy consumption in China are published within the "China's Energy Statistical Yearbook (State Statistical Bureau, P. R. China (1998,2001))". The statistics from 1991-1996 were published in 1998, and that of 1997-1999 in 2001, with listing energy matrix tables of energy use sector and fuel type by province. In this study based on the energy matrix tables by province, a more accurate estimation of residential energy use can be performed than by simply using the national total energy matrix tables from the former energy yearbooks. In this study the area "China" excludes Taiwan and Honking, and consists of 30 provinces including four particular cities: Beijing, Shanghai ,Tianjin and Chongqing.

3-2 Energy Consumption

In this paper we analyzed the residential energy consumption, emissions of greenhouse gases and air pollutants based on the "China's Energy Statistical Yearbook". Provincial data is estimated from the 1995-1999 figures, and trend analysis of the national total from the 1991 to 1999 data. The energy demand sector of the yearbook has the "Residential Consumption" sector and for 1995-99 it is separated into the sub sectors "Urban" and "Rural"[1]. Therefore allowing the analysis of the features of urban and rural areas, for which the energy demand structure is different as discussed later on. Provincial analysis is by sub sector and also by fuel type. In addition this study includes an estimation of the division of consumption by end-use for 1995. Energy consumption, GHGs and air pollutant emissions from the residential sector have been estimated and reported before as a part of various emissions inventory studies. The variation of the energy consumption in these features by urban and rural sector is reported in Hu X. and Jiang K.(2001). But this study might be the first case of the detailed emissions analysis on the provincial level by urban and rural area.

In this study energy consumption is converted to units of annual peta joule (PJ[2]) low calorific value base from the original yearbook unit of TCE (Tonne Coal Equivalent, 7000kcal /kg low calorific value standard coal base). The low calorific value by fuel type is shown in Table-1[3]. Electricity units are also converted, i.e. 860kcal/kWh to 3596kJ/kWh as a secondary energy base. For data comparison the primary energy base of 2773kcal/kWh is equivalent to 11610kJ/kWh, which assumes 31% power generation efficiency.

Table 1 Low calorific value by fuel type

Fuel Type	Unit	Value	Unit	Value
Raw Coal	kJ/kg	20908	kgce/kg	0.7143
Cleaned Coal	kJ/kg	26344	kgce/kg	0.9000
Other Washed Coal	kJ/kg	12545	kgce/kg	0.2857
Briquettes	kJ/kg	15693	kgce/kg	0.6068
Coke	kJ/kg	28435	kgce/kg	0.9714
Coke Oven Gas	kJ/cu.m	17562	kgce/cu.m	0.5929
Other Gas	kJ/cu.m	8836	kgce/cu.m	0.3477
Other Coking Products	kJ/kg	33663	kgce/kg	1.1505
Kerosene	kJ/kg	43073	kgce/kg	1.4714
LPG	kJ/kg	50179	kgce/kg	1.7143
Refinery Gas	kJ/kg	45998	kgce/kg	1.5714
Other Petroleum Products	kJ/kg	38347	kgce/kg	1.3110
Natural Gas	kJ/cu.m	38931	kgce/cu.m	1.3300
Heat	kJ/MJ	1000	kgce/MJ	0.0341
Electricity	kJ/kW・h	3596	kgce/kW・h	0.1229
Biogas	kJ/cu.m	20908	kgce/cu.m	0.7140
Stalks	kJ/kg	14635	kgce/kg	0.5000
Firewood	kJ/kg	16726	kgce/kg	0.5710

3-3 Emission Estimation

The emission factors of CO_2, SO_2, NO_x, and Sulfur content by fuel type are shown in Table 2. In this study, the indirect emissions from electricity and heat consumption are taken into account. The NO_x emission factors of firewood and stalks (crop residues) are quoted from Streets D.G.,Waldhoff S. T.(1998). NO_x emission factors can be given not only by fuel type but also by matrix of furnace type if energy consumption by furnace type is prepared. In this study an energy matrix of end use and fuel type is estimated for China as a whole as shown in Fig 8-10 later on.

However, this cannot be estimated at a province level, therefore emission factors by matrix of end-use and fuel type could not be applied to this study, but only by fuel type as shown in Table2. More detailed and accurate estimations using emission factors by end-use and fuel type are to be considered in the further studies.

Table 2 Emission Factor by fuel type

	CO_2	No x	SO_2	Sulfur Content	Sulfur Air Emission Rat
	kg/GJ	kg/10^8kJ	kg/GJ	%	%
Raw Coal	86.3	10.1	0.413	0.460	77.5
Cleaned Coal	90.4	10.1	0.327	0.460	77.5
Other Washed Coal	89.8	10.1	0.687	0.460	77.5
Briquettes	103.5	10.4	0.529	0.460	77.5
Coke	103.5	10.0	0.405	0.610	77.5
Coke Oven Gas	45.1	10.6	0.004	0.008	100.0
Other Gas	179.2	10.8	0.005	0.005	100.0
Other Coking Products	102.3	9.7	0.807	1.400	100.0
Kerosene	64.4	5.0	0.032	0.004	100.0
LPG	59.0	17.0	0.001	0.002	100.0
Refinery Gas	59.0	17.5	0.004	0.009	100.0
Natural Gas	50.3	5.0	0.000	0.000	100.0
Biogas	83.2	5.0	0.000	-	100.0
Stalks	77.5	4.5	0.038	0.070	-
Firewood	106.8	9.1	0.038	0.070	-
Electricity	307.0	0.4	0.144	-	-
Heat	113.0	0.2	0.051	-	-

4. Energy Consumption State

4-1 Cross Check with the previous studies

Residential energy consumption (including biomass fuel) by fuel type in urban and rural sectors in China from 1991 and 1995 to 1999 are shown in Fig.1 (low calorific value and secondary energy base). Total consumption in 1999 is 10261 PJ, of this 2003PJ is urban and 8259PJ rural, corresponding to shares of 20% and 80% respectively. Hu and Jiang.(2001) estimated consumption using 1995 data and calculated a total of 410.7MTCE, i.e. 12036PJ, urban of 84.1MTCE i.e. 2464PJ and rural of 326.6MTCE, i.e. 9572PJ in primary energy base. Our results in 1995 are total 11567PJ, urban 1968PJ and rural 9599PJ in secondary energy base. Our results, if converted to the primary energy base, using 2773kcal/kWh i.e. 10467kJ/kWh, (derived from Hu and Jiang (2001)), become total 12368PJ, urban 2426PJ and rural 9942PJ. The results of the two studies are similar and it is acknowledged that our study and theirs are based on the same energy statistics.

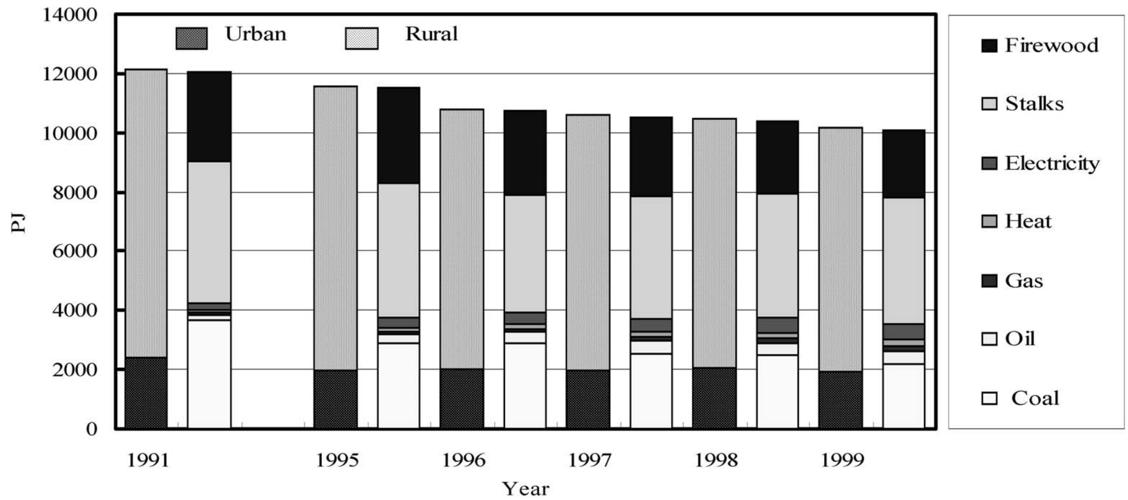

Fig. 1 The residential energy consumption trend 1991 to 1999 in China (low calorific value and secondary energy base)

4-2 Fundamental features of residential energy consumption in China

Fig2 shows energy consumption and emission components by fuel and electricity. The remarkable feature of residential energy consumption in China is biomass fuel use. In rural areas of China, large quantities of biomass fuel such as stalks and firewood are used in residential houses for cooking and space heating. Stalks comprised 52% and firewood 28% of fuel use in 1999, with 80% biomass as secondary energy in rural areas. In urban areas no biomass is used. As a whole 65% of the total area is biomass. Another prominent feature is coal use. In urban areas this comprised 63% (including briquettes coke) in 1995, decreasing to 44% in 1999, but it is still the dominant fuel in urban . In 1999 22% of the total secondary energy of all area total is from coal and coal products. By comparison electricity consumption is only 5% of all area total, in urban areas 16% and in rural only 3%. Oil product use is rarer with kerosene only accounting for 0.3% of the total in 1999.

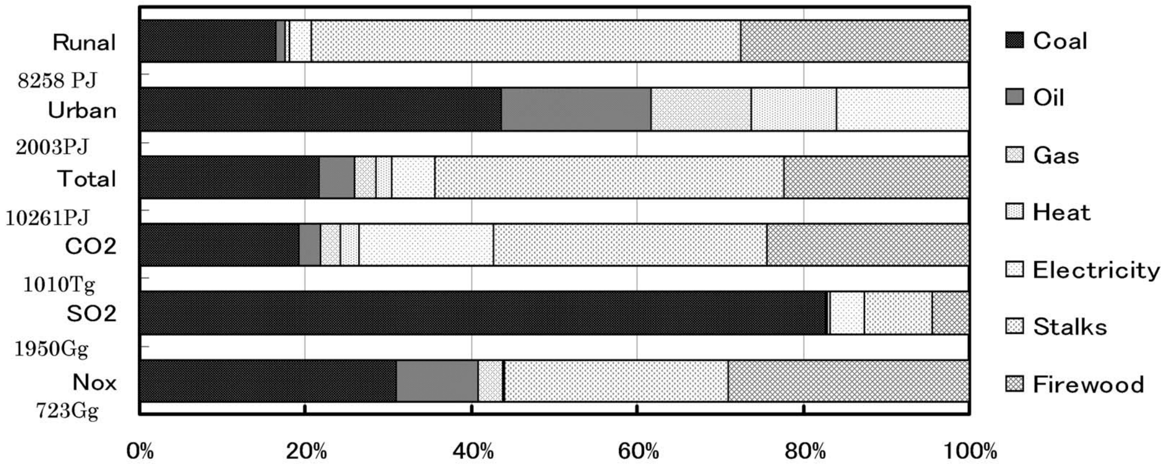

Fig. 2 Residential energy consumption and emissions of CO_2, SO_2 and NO_x by fuel type in 1999

4-3 Annual trend of residential energy consumption

Total energy consumption in China including biomass energy has increased from 30EJ, 1015 MTCE in 1991 to 37EJ,1264MTCE in 1999. The average annual growth rate of total energy consumption in this period is 2.8% (State Statistical Bureau, P. R. China, 1998 and 2001). However, residential energy consumption including biomass energy has decreased continuously from 11567PJ in 1991 to 10261PJ in 1999, as shown in Fig1. Significant changes in this period were a decline in coal use and a growth in that of electricity and gas.

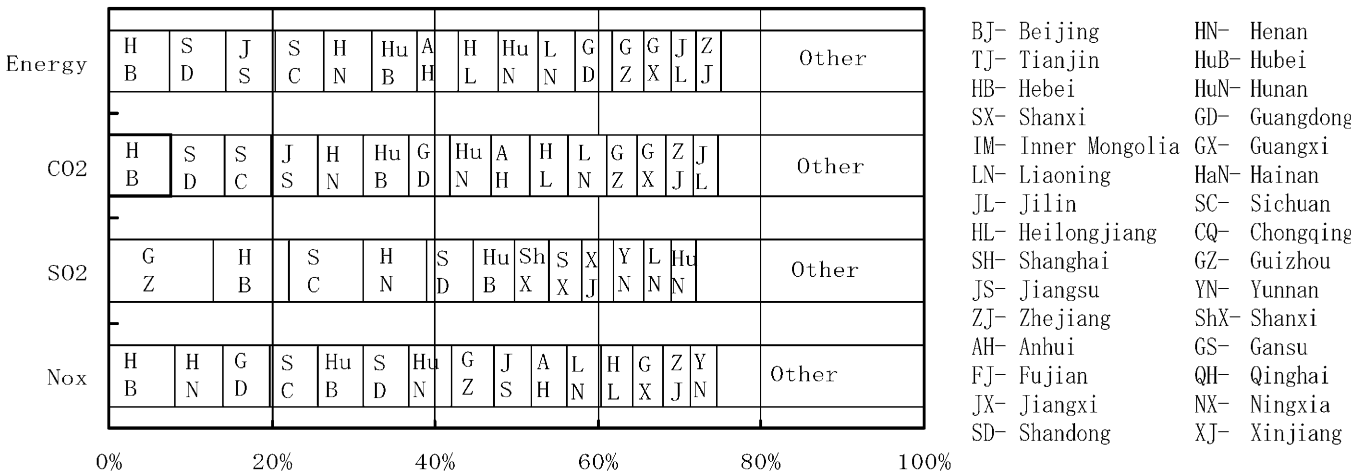

Fig. 3 Residential energy consumption and emissions of CO_2, SO_2 and NO_x by province in 1999

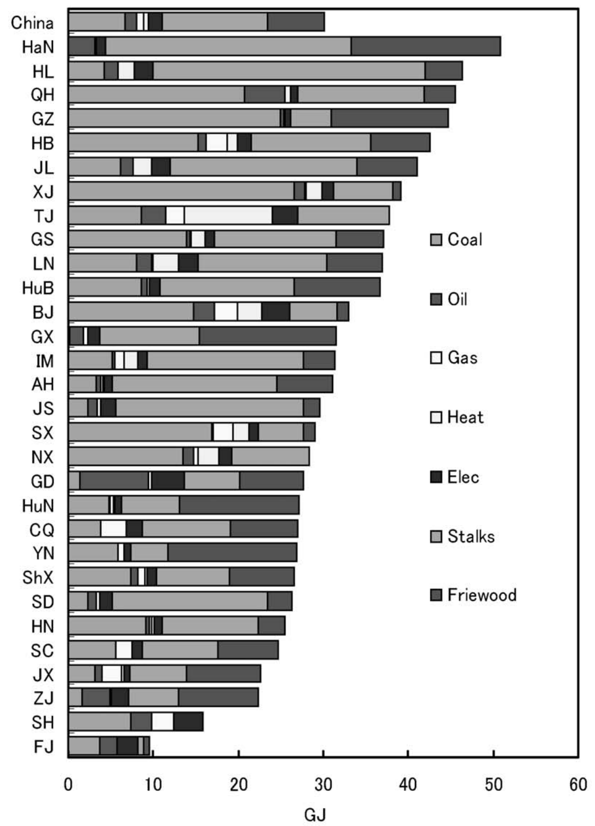

Fig. 4 Residential energy consumption per household by province and fuel type in 1999 (low calorific value)

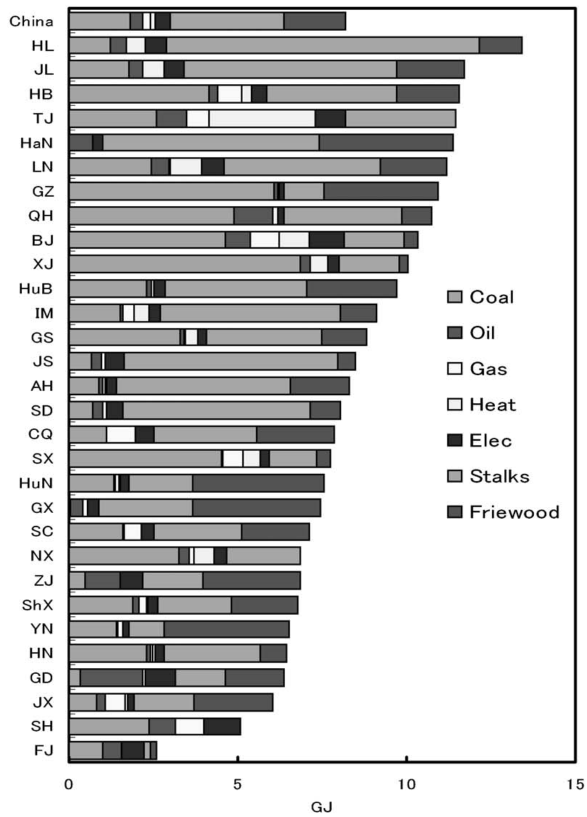

Fig. 5 Residential energy consumption per capita by province and fuel type in 1999 (low calorific value)

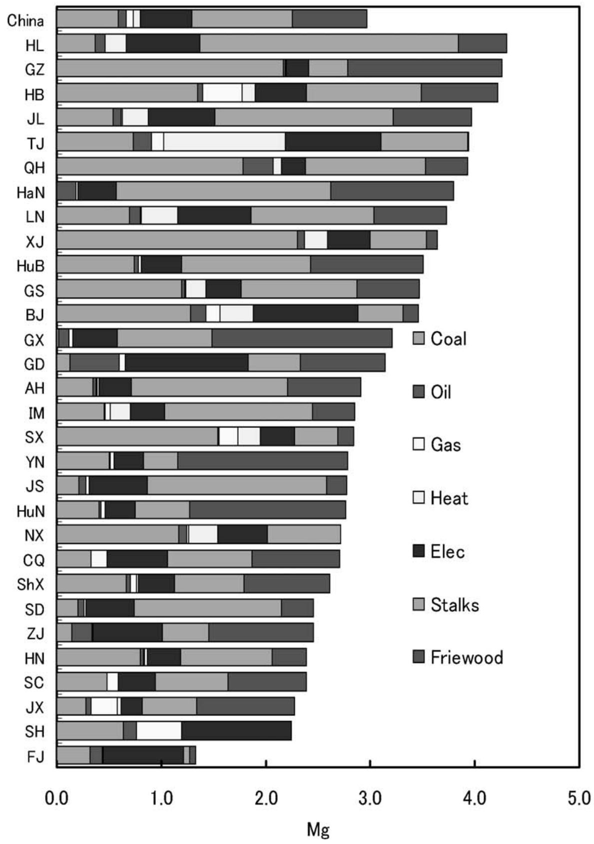

Fig. 6 CO_2 emission per household from residential energy consumption in 1999

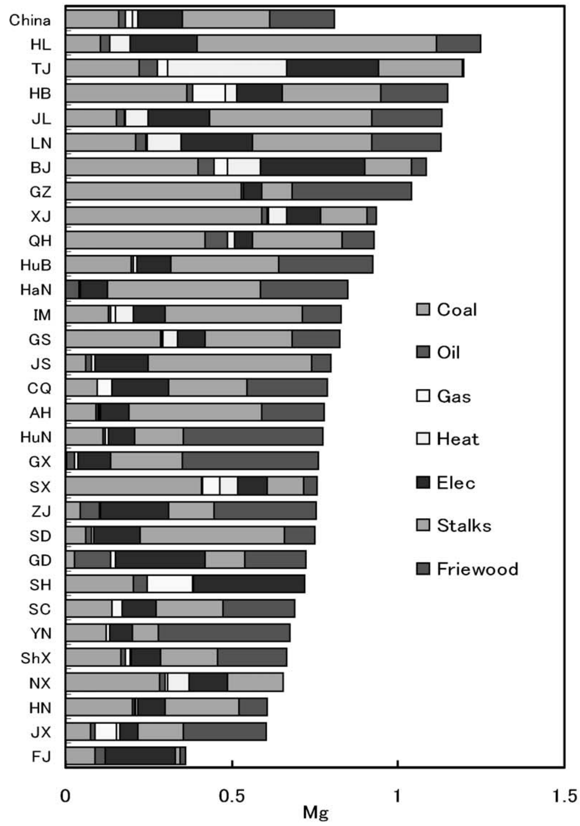

Fig. 7 CO_2 emission per capita by province from residential energy consumption in 1999

4-4 Regional Variance

One of the original points in this study is the regional analysis of energy consumption and emissions by province, as shown in Fig3-7. The order of provinces in scale of energy consumption and emissions are similar for each individual component. “Hebei” is the biggest source area with the exception of SO_2. “Shangdong”, “Jangsu”, “Sichuan” and “Henan” are all areas of sizeable energy consumption and emissions as shown in Fig3.

Energy consumption and CO_2 emissions per household or per capita by province are shown in Fig 4 to 7. Per household and per capita consumption levels are both generally higher in the northern or inland areas, where space heating loads are higher. In “Shanghai”, a well developed high income area, per capita and per household energy consumption and per household $C0_2$ emissions are second lowest only to “Fujian”, an undeveloped low income area. The primary reason is that in Shanghai biomass fuel use with low energy efficiency is rare, in 1999 it comprised zero percent of total energy use.

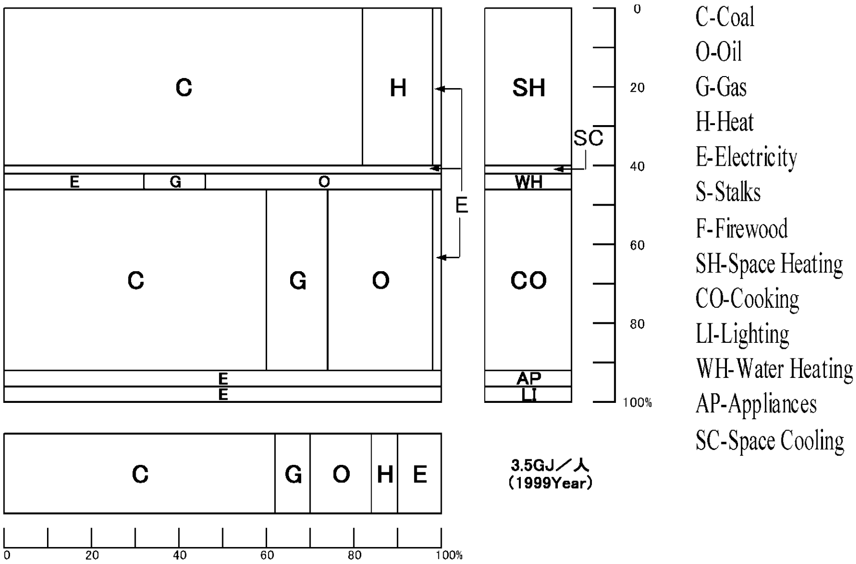

Fig. 8 Residential energy matrix in urban in China in 1999

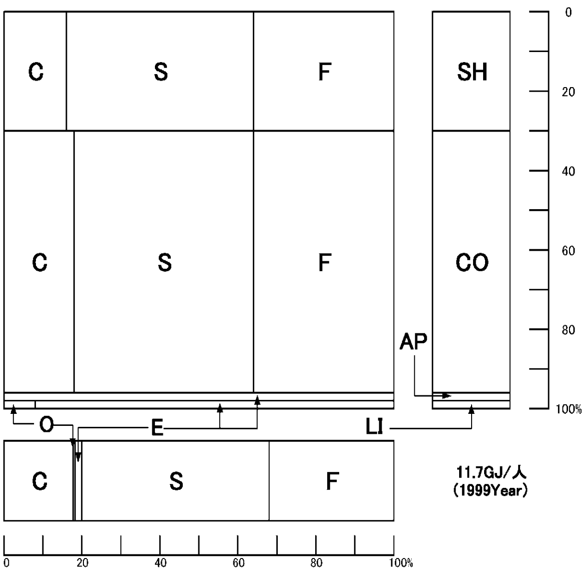

Fig.9 Residential energy matrix in rural in China in 1999

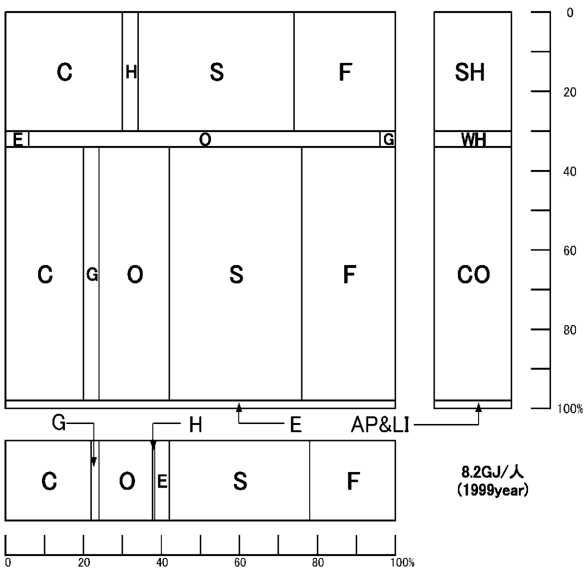

Fig.10 Residential energy matrix in China in 1999

4-5 Residential energy matrix

This study as mentioned above has analyzed by urban /rural sectors, fuel type and province. Thermal end use type is also an important factor in analyzing residential energy use. Thermal End use consists of five types: space heating; space cooling; water heating; (electricity) appliance and lighting. Referring to the end use component by fuel type in the residential energy matrix for urban and rural areas in 1995 in China by Hu and Jiang(2001), we tried to estimate the residential energy matrix in 1995. As seen in Fig8 to 10 for urban, rural and total cooking energy consumption is the dominant use in every area.

In rural areas it accounted for more than half and in urban 43%. It is said that in case of very low or minimal levels of residential energy consumption, the end-use energy consumption of cooking would be particularly dominant generally in the world, as it is indispensable. China case, particularly in Fig9 about rural areas, would be a typical figure. This can be compared to the residential energy use situation in Japan where hot water supply or appliances would produce one of the dominant part of end-use.

4-6 International comparison

Fig.11 to 14 show an international comparison with Japan on a per capita energy and emission basis. The energy consumption level per capita in China is obviously lower than Japan even if including low efficiency biomass use in rural areas. Difference about emissions are smaller, particularly SO_2 emission per capita in China is much bigger than Japan. In 1999 China's residential energy level per capita is 52% of that of Japan, and is comparable to Japan in 1976. The average annual energy consumption per household in China in 1999 is 30.2 GJ, close to the level in Japan in 1979.

The thermal efficiency of biofuel for cooking in rural areas is only under10%[4]. Hence energy consumption and emissions of air pollutants and GHGs in rural areas are large at present. Assuming the efficiency of biofuel for cooking could be improved to 40%, the average annual energy consumption in rural areas would be 7.27GJ/ capita, 68% of the level in 1999. That assumed level is 46% of Japanís in 1999.

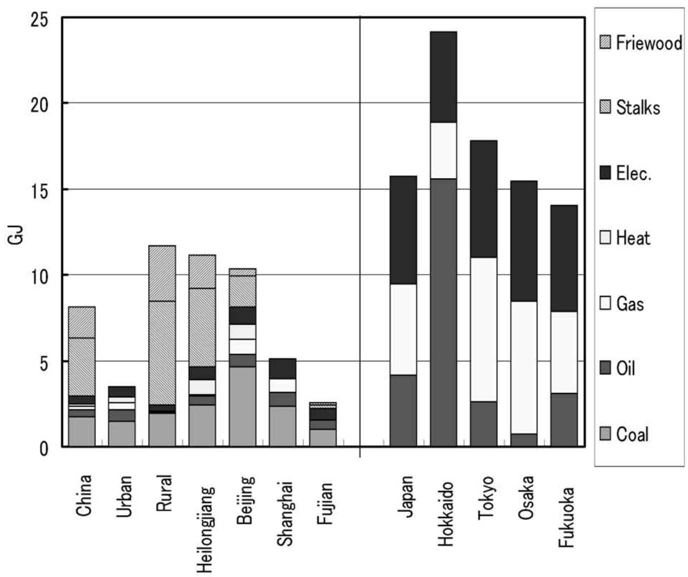

Fig. 11 Energy consumption per capita in China and Japan in 1999

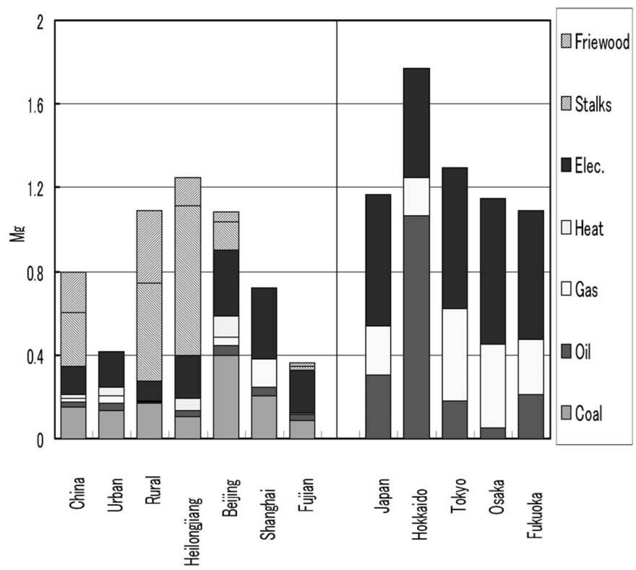

Fig. 12 CO_2 emission per capita in China and Japan in 1999

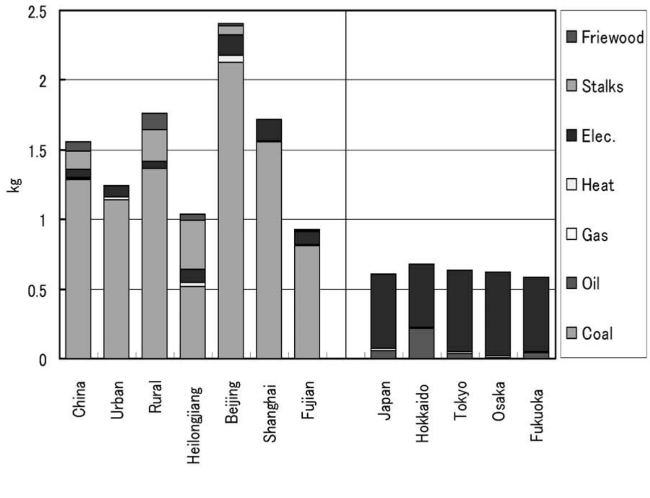

Fig. 13 SO_2 emission per capita in China and Japan in 1999

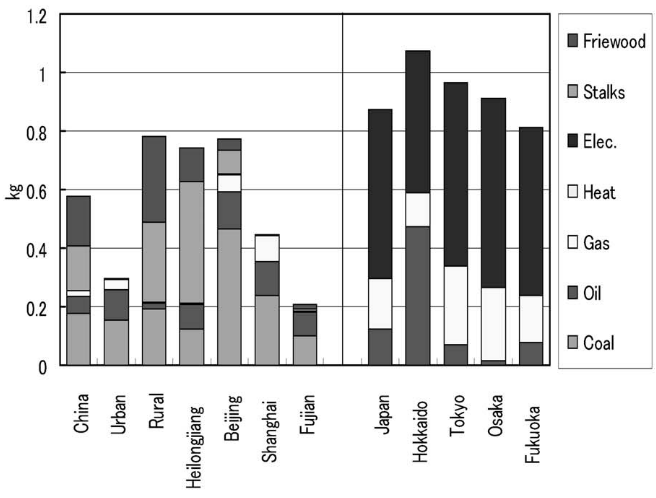

Fig. 14 NO_x emission per capita in China and Japan in 1999

5. Conclusion

By this fundamental study based on the “China Energy Statistics Book”, present state of residential energy consumption in China is analyzed. Distinctive features in urban areas and rural areas are clarified through the provincial data analysis. By the comparison with the Japan state, we could grasp the relative stage of the residential energy consumption in China. But this is only the first step in providing a fundamental analysis, to understand the interrelation between determinant factors which will affect the future trend, further analysis is required.

Acknowledgments

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Notes

1. Urban : Based on the population of non-agricultural area by China government statistics
   Rural : Based on the population of agricultural area by China government statistics
2. PJ(peta joul) is an energy unit: peta=10 powered 15, 1cal=4.1868Joul
3. In the China’s energy statistics energy consumption in TCE unit is simply estimated from the process biomass fuel consumption multiply calorific value absolute dry base, which means biomass fuel consumption data is absolute dry base. About biomass energy consumption data this study followed with the TCE unit amount in China’s energy statistics. But if assumed the water content on the biomass fuel consumption data, it will become smaller by the water content rate.
4. Hu and Jiang(2001), also in Goldemberg J. et al(1988),p231

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