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Direct and Indirect Energy Consumption of Households in Beijing

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Problem Description

Objective

Evaluate the direct and indirect energy use of different households at different levels of development in Beijing today and make projections for the near-term future based on the observations, as well as recommendations for improving energy efficiency.

The following questions should be considered in the thesis:

1. How are people in Beijing living today? What is the typical situation? Are there any patterns we can observe? What are the differences among socioeconomic groups?

2. What households should you sample to get a representation both of current energy consumption and of likely developments, assuming that the entire populations moves up in income and hence resembles the energy lifestyles of the well-off today?

3. How large are direct and indirect energy use, and what activities/items are they connected to?

4. Provide an estimate of the overall direct and indirect energy use in Beijing.

5. Make some projections of the energy use.

Assignment given: 22. January 2008
Supervisor: Edgar Hertwich, EPT

Preface

With the handing in of this thesis I complete my MSc degree in Energy and Environmental Engineering at the Norwegian University of Science and Technology (NTNU).

Although frustrating at times, the five-month process of accomplishing this thesis has been interesting and exciting. I have been very lucky to be given the chance to travel to Beijing to do field work. The trip was a wonderful experience that I have greatly benefited from, both professionally and personally.

A very big thank you goes to Professor Edgar Hertwich and Dr Jingru Liu for their guidance and for giving me the opportunity to visit and work at the Research Center for Eco-Environmental Sciences (RCEES), Chinese Academy of Sciences. I greatly appreciate the kindness and helpfulness of everyone I met at the RCEES. The Industrial Ecology Programme at NTNU generously provided financial support for my trip, for which I am very grateful. I would like to thank Mr Yao Shi for his great help with doing field work for my thesis. I would also like to thank Dr Glen Peters for helping me get started with the input-output calculations.

Last, but not least, a warm thank you goes to my girlfriend Liv Ragnhild for her unfaltering support and for always keeping faith in me.

Trondheim, 22 June 2008

Anders Arvesen

Anders Arvesen

Table of contents

Abstract

China's economy has grown at remarkable rates in the last three decades, bringing about big improvements in people's quality of life. On the downside, the increased economic activity has contributed to serious environmental problems, many of which are related to the country's energy system. Focusing particularly on Beijing, this study aims at illuminating how income growth and lifestyle changes relate to energy use in the society. An extended input-output analysis is applied to estimate the direct and indirect household energy consumption (HEC) of Beijing households at different levels of development in the year 2005. Using observations of how HEC varies across income groups in 2005 as a basis, projections of HEC towards 2015 are made. According to the results, the total HEC in Beijing amounts to 42% of the total direct energy use occurring in all sectors within Beijing's geographical boundaries. Hence, a significant portion of the energy use in the society can be linked with consumer activities. For urban residents, indirect influences on energy use are found to be more than three times greater than the direct influences. Mainly due to growing incomes, total HEC in urban Beijing will grow substantially in the period 2005-2015, even with overall efficiency improvements corresponding to the central government's targets. The results indicate that the share of transport related energy use to total HEC will increase significantly. Without major efficiency improvements, huge increases in transport related energy use is to be expected towards 2015. Air conditioners will be the most important single electrical appliance contributing to increased residential electricity consumption in the near future.

Due to significant uncertainty, the figures should be taken as rough guides to the magnitude of different types of energy use only. Nonetheless, it is the author's opinion that the study produces valuable insights that can add to our understanding of the underlying drivers of energy use in the Beijing society. The estimates are considered sufficiently accurate to serve as a basis for making some recommendations for improving the energy efficiency of the society. Based on the findings of the study, the author calls on central and local governments to: 1) Further incorporate the important role of consumer behaviour and lifestyle into energy conservation policies; 2) Make strong efforts to mitigate transport related environmental problems, focusing attention both on producers and consumers; 3) Give high priority to constructing energy efficient buildings; 4) Further strengthen and expand the performance standard and labelling scheme for electrical appliances; 5) Consider imposing constraints on the promotion of consumerism by the mass media and advertising industry.

Sammendrag

Kinas kraftige økonomiske vekst de siste tretti år har ført til formidable forbedringer i innbyggernes livskvalitet. Velstandsøkningen har imidlertid en høy pris i form av omfattende miljøproblemer. Mange av miljøproblemene er knyttet til landets energisystem. Denne studien har til hensikt å analysere energibruk i Kinas hovedstad, Beijing. Mer spesifikt er målet å belyse hvordan velstandsvekst og endringer i livsstil er relatert til energibruk i samfunnet. En utvidet kryssløpsanalyse tas i bruk for å estimere direkte og indirekte energibruk for husholdninger ("Household Energy Consumption", HEC) i Beijing i 2005, med spesielt fokus på hvordan energibruken varierer med inntekt. Observasjonene av husholdningers energibruk i 2005 brukes videre til å framskrive energibruken de neste ti år. Ifølge resultatene utgjorde total HEC i Beijing 42% av all direkte energibruk i alle sektorer i Beijing i 2005. En betydelig del av energibruken i samfunnet kan altså relateres til forbrukeraktiviteter. I urbane områder er forbrukernes indirekte innvirkning på energibruk i samfunnet mer enn tre ganger så stor som den direkte innvirkningen. Hovedsakelig som følge av inntektsøkninger kommer total urban HEC i Beijing til å øke vesentlig i perioden 2005-2015, selv med en forbedring i samlet energieffektivitet tilsvarende regjeringens målsetninger for den nasjonale økonomien. Energi knyttet til transport skiller seg ut som den hovedtypen energibruk hvor økningen vil bli størst, når forbedringer i energieffektivitet ikke tas hensyn til. Av elektriske apparater er klimaanlegg det enkeltapparatet som vil bidra mest til økt elektrisitetsforbruk i boliger de nærmeste årene.

Studien belyser underliggende drivkrefter for energibruk i samfunnet, og kan hjelpe oss både med å vurdere størrelsen på framtidig energibruk og å evaluere muligheter for å begrense energibruken. Beregningene i studien er beheftet med betydelig usikkerhet, men resultatene anses å være tilstrekkelig nøyaktige til å danne grunnlag for anbefalinger for å begrense energibruken. Forfatteren vil, med grunnlag i funnene som er gjort, gi følgende anbefalinger til nasjonale og lokale styresmakter: 1) Miljøkonsekvensene av forbrukeres adferd og livsstil bør ytterligere innlemmes i politikkutformingen, blant annet ved økt bruk av økonomiske insentiver for å stimulere til miljøvennlige forbruksmønstre; 2) Bruk av politiske virkemidler for å begrense energibruk og forurensning knyttet til privat transport bør stå i forhold vekstpotensialet og miljøulempene. Det er avgjørende at politikken setter tilstrekkelig fokus på både teknologiske forbedringer og forbrukeradferd; 3) Konstruksjon av energieffektive bygninger bør gis høy prioritet; 4) Kinas energimerkeordning for elektriske apparater bør styrkes og utvides ytterligere; 5) Det bør vurderes å innføre begrensinger på promotering av materialistisk forbrukskultur i massemedia og reklame.

List of figures

List of tables

1 Introduction

The Chinese economy has been subject to major transformations in the last three decades. Since economic reform started in 1978, gross domestic product has grown at an average annual rate of almost 10%, bringing about deep changes for the Chinese people. As a result of increased spending power and heavy public investments in infrastructure, an increasing share of the Chinese population can enjoy lifestyles resembling that of Western countries. Not having to limit their consumption strictly to the necessities of life, an increasing number of Chinese citizens aspire to lives with diversified consumption, high levels of mobility, large living floor space and a large number of electrical appliances. These developments have contributed to big improvements in people's quality of life. On the downside, increased economic activity has contributed to serious environmental problems, which are among the most severe of any major country (Liu and Diamond 2005). In a global context, China's rapidly growing CO_2 emissions is a major reason for concern. According to one estimate, China surpassed USA and became the world's largest emitter of CO_2 in 2006 (MNP 2007). On a national and local level there is a concern about local air pollutants, as well as about a wide range of other environmental problems, including water pollution and shortages, desertification, biodiversity losses and trash accumulation (Liu and Diamond 2005).

Many of China's environmental problems are related to the country's energy system (Liu and Diamond 2005). Coal, constituting 77% of China's total energy production (NBS 2006a), is the backbone of the Chinese energy system and the primary cause of China's energy related environmental problems (IEA 2007). In addition to causing emissions of the greenhouse gas CO_2, burning of coal also causes emissions of SO_2, which damages health and is the main precursor of acid rain, and NO_x, also a precursor of acid rain and an important contributor to ground-level ozone creation. Coal-related emissions of CO, particulate matter and mercury may lead to serious health problems (Aunan et al. 2006). Next to the burning of coal, road traffic is a dominant and ever growing source of emissions, especially in the cities (IEA 2007). In Beijing, air quality has improved in recent years, but is still poor. Vehicles' emissions now constitute the main source of air pollution in Beijing (Liu et al. 2007).

Recognising the vital role of energy efficiency in addressing environmental problems and securing a safe energy supply, improving energy efficiency has long been an area of concentration for the Chinese government. Specific energy improvement targets have been set, both for the industrial, transport and building sectors. In the industrial sector, important progress has been made in the previous decade. However, the energy efficiency picture is mixed, and much of China's industry is still characterised by the use of outdated and inefficient technology (IEA 2007). In 2003, the average efficiency of coal-fired power production in China was 33%, significantly lower than the average efficiency in e.g. Japan (42%), the Nordic countries aggregated (40%) and Germany (39%) (Graus et al. 2007). Regarding transport, a number of measures have been introduced to cope with heavy air pollution and congestion problems in Beijing. The measures include major investments in improving transport infrastructure, stricter new-car emissions standards (compared to other regions of China) and the introduction of fuel substitutes for buses and taxis (Liu et al. 2007). In the buildings sectors, China lags behind developed countries in constructing energy efficient buildings. The average urban residential consumption of heating in China is roughly two to three times as much as that required by new standards in European countries with similar climatic conditions (Yang and Kohler 2008). According to a survey conducted by the

Chinese Ministry of Construction, only 23% of the newly constructed buildings from 2001 to 2004 were in compliance with energy-saving codes (Yang and Kohler 2008).

The Chinese government has set ambitious goals for improving the overall energy efficiency of the society. The 11th Five-Year Plan (2006-2010) aims to reduce the energy intensity of the country by 20% between 2006 and 2010 (IEA 2007), which is equivalent to an annual reduction of 4.66%. In the longer term, the government aims at quadrupling the per capita GDP from 2000 to 2020, while only doubling primary energy consumption (IEA 2007). During the whole period 2000-2006, energy intensity declined with only 0.42%. Over 2005, the energy intensity declined with 1.30% (NBS 2006b). It should be noted that China's coal consumption in 2000 may suffer from significant under-reporting (Akimoto et al. 2006; Peters et al. 2007), and thus the decline in energy intensity between 2000 and 2006 may be larger than suggested by the official statistics. Nevertheless, there is little doubt that reaching the government's energy efficiency targets will be challenging.

While there is no doubt that improving the efficiency of production systems is essential if sustainable development is to be achieved, it is also becoming increasingly evident that environmental gains achieved on the production side of the economy are being offset by trends on the demand side (UNEP 2002). In recognition of this fact, strong voices have argued that purely technological approaches will not be sufficient to achieve sustainable development, and that we also need to focus attention on lifestyle and consumer behaviour. At the World Summit on Sustainable Development in Johannesburg in 2002, it was stated that "Fundamental changes in the way societies produce and consume are indispensable for achieving global sustainable development" (UN 2002), highlighting the importance of focusing both on sustainable consumption and production. Within the field of industrial ecology, implications of consumer behaviour and lifestyles changes on environmental pressures have been a topic of investigation for many years.

This study focuses on the household energy consumption (HEC) of households in Beijing, with the principal aim of illuminating some of the underlying drivers for energy use in the Beijing society. The HEC consists of two parts; direct HEC and indirect HEC. Direct HEC can be defined as the energy use of a good or service occurring while the actual good or service is being used by the consumer. In this study, the direct HEC includes the use of electricity, heat and fuels in households, as well as the use of fuels for private transportation. Energy use associated with producing and distributing goods and services to consumers are referred to as indirect HEC. Improving our understanding of how lifestyles and human aspirations and needs relate to energy use in the society is important for several reasons. It may help in assessing future levels of energy use, and it can provide scientists and decision makers with insights that are useful for evaluating opportunities for reducing the energy intensity of the society.

The main research questions of the study are defined as follows:

- How are people living in Beijing today, and what are the differences among socioeconomic groups?
- How large are the direct and indirect energy consumption of households, and what types of activities and purchases are they connected to?
- Based on observations of how HEC varies among socioeconomic groups today, what can be said about likely implications of future income growth and lifestyle changes on energy use?

In the following chapter, some selected aspects of how people are living in China and Beijing today are presented and discussed. Emphasis is put on household characteristics that are important in the perspective of HEC, and on how these vary with time and among socioeconomic groups. Next, Chapter 3 presents the methodology used in this study, including a brief presentation of field work that has been carried out in Beijing. The final results are presented and discussed in Chapters 4 and 5, respectively. The main findings and final conclusions are summed up in Chapter 6.

2 Living in Beijing

Beijing is the capital and the political centre of China. As the capital of an increasingly important player in the global economy, the city has been subject to an increasing international interest in recent years. As the host of the 2008 summer Olympic Games, Beijing is in the spotlight as never before. This chapter looks at characteristics of people's life in Beijing and in China, putting emphasis on aspects that are of relevance in the perspective of household energy consumption (HEC). Developments at the local and nationwide level cannot always be evaluated independently, and for some data used in this study, specific numbers for Beijing are not available. Therefore, although the main emphasis is put on Beijing, some numbers representing a China national average are also presented.

Section 2.1 concerns issues that can be related to population numbers and city structure, including urbanisation and urban sprawling. Trends in consumption levels and patterns are the topic of Section 2.2, while Section 2.3 concerns personal mobility. Finally, Section 2.4 gives a presentation and discussion on the use of direct energy in households.

Much of the data presented in Chapter 2 originates from the Chinese Survey of Consumer Expenditure (SCE), of which results are presented in the annual publications China Statistical Yearbook and Beijing Statistical Yearbook. In the yearbooks, the survey results for Beijing are typically presented by five income quintiles. Each income quintile makes up 20% of the households in the survey. Supplementary data on the characteristics of the five income quintiles (i.e. socioeconomic groups) are given in Appendix A.

2.1 Population and city structure

China's total population passed 1.3 billion in 2005. In 2007, nearly 20% of the world population lived in China. As a result of several factors, including family planning policies, urban fertility rates in China are low. After 1978, gradual relaxations in restrictions on migration in China have allowed for rapid urbanisation to occur (UN 2007; UNFPA 2007). On average, Chinese cities have doubled their size in the past 20 years. Natural increase, peri-urbanisation (transformation of rural areas into urban areas) and rural-urban migration all contribute to growth in China's urban population (IEA 2007). At the national level, 43.9% of the population were living in urban areas in 2006, compared with only 26.4% in 1990 and 17.9% in 1978 (NBS 2007). In 1978, Beijing's total population numbered 8.7 million people. In 1990, the population had increased to 10.9 million and in 2006 to 15.8 million (BMBS 2007). With its official city boundaries also embedding districts with more rural than urban residents, Beijing had a share of 15.7% rural residents in 2006 (BMBS 2007). The share of the population classified as urban or rural from 1990 to 2006 is depicted in Figure 2-1, for China and Beijing, respectively.

More so than in other developing countries, peri-urbanisation has been an important characteristic of urbanisation in China. Structural and physical changes in rural areas have blurred the lines between rural and urban settlements, introducing the aspect urban-ness in areas traditionally classified as rural (UNFPA 2007). This seems to be particularly true for Beijing. Since the 1990s especially, there has been a distinctive transformation of rural areas into urban areas in Beijing. Urban and rural socioeconomic networks have been interwoven, creating peripheral zones where various socioeconomic activities are happening simultaneously (Lei 2007). Also, the statistics show clear signs of Beijing rural residents in some aspects enjoying lifestyles that in a national perspective are typical for urban households. For example, Beijing rural residents have a much higher income and own more durable goods than the average rural resident in China. This will be further discussed in Sections 2.2.1 and 2.4.2.

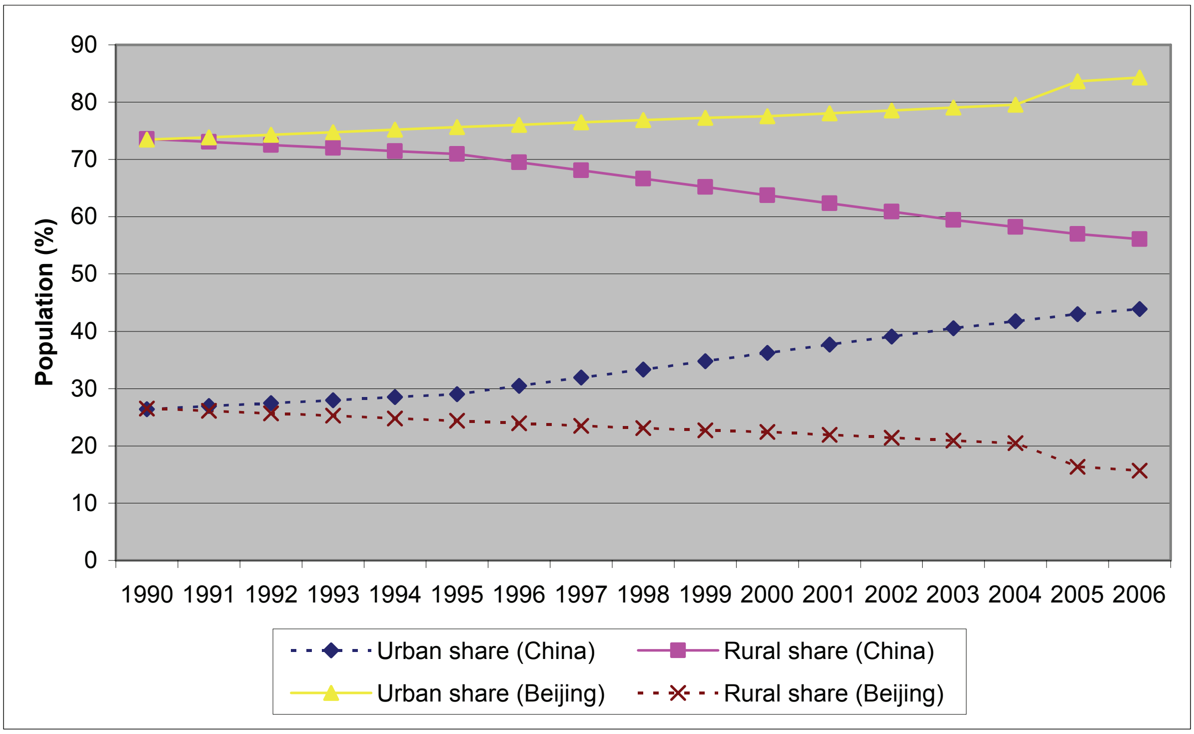

Figure 2-1: Share of populations classified as urban and rural 1990-2006 (BMBS 2007; NBS 2007)

As can be seen in Figure 2-1, the trend for the urban share in Beijing is close to linear from 1990 to 2004. The average annual growth rate in this time period is 0.6%. From 2004 to 2005 however, there was a sudden increase in the urban share by 5.1%, much higher than the average annual increase from 1990 to 2004. It is not clear whether this abrupt change in the urban population growth trend represents an actual change or if it is caused by non-consistency in the use of definitions and methodologies in household surveys. It is conceivable that as the distinction between urban and rural settlements are blurred, the urban-rural division becomes more artificial, and achieving consistency over time when classifying households becomes more challenging.

One consequence of an increasing income disparity (Section 2.2.1) between rural and urban areas in China has been a large floating population. Although these residents officially are seen as temporary residents, many of them remain year after year. In Beijing in 2003, the floating population numbered four million residents, among whom three million had been in the city for more than six months (Li et al. 2007). They come from rural areas of Beijing, as well as from other cities and provinces, and typically seek jobs in labour-intensive manufacturing industries, construction sites or service sectors (Lei 2007). These residents suffer from low incomes, and in some aspects they live a separate life to the registered Beijing residents. In addition to having to deal with difficulties in life associated with low incomes, the temporary residents are entitled to few of the rights enjoyed by the permanent population. For example, they are excluded from the public housing provision system and they do not enjoy the benefits of schooling as permanent residents do (Lei 2007). It has been estimated that 60% of the floating population in Beijing live in enclaves of old farm houses in the outer urban fringe. These 'migrant villages' typically suffer from being overcrowded and of inadequate underground sewerage and drainage systems (Gu and Shen 2003), and the location of the migrant villages in the peripheries of urban Beijing often makes commuting by walking or biking exhaustive (Ahmed et al. 2008). The Chinese SCE does not include the floating population (Ravallion and Chen 2007).

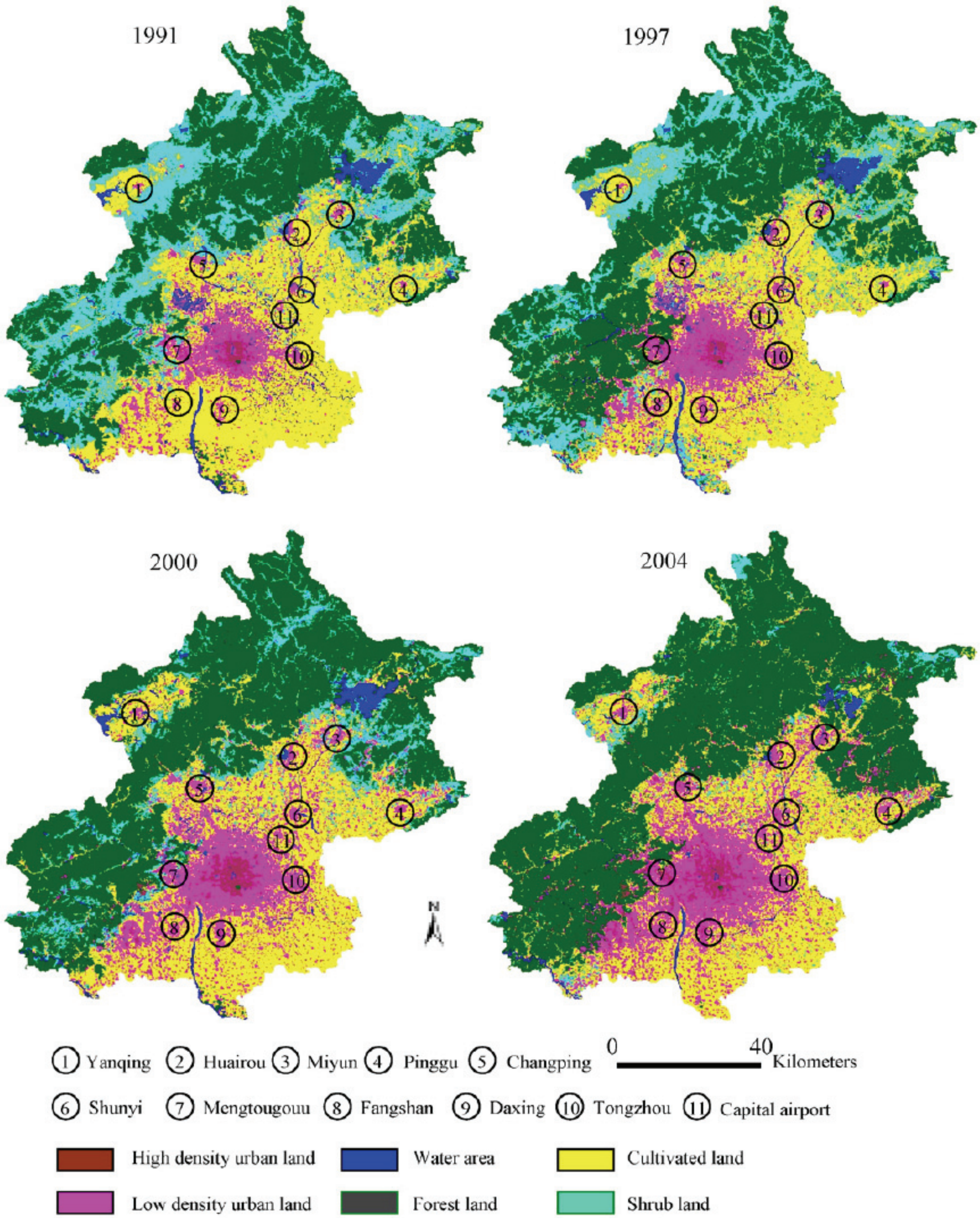

Figure 2-2: Land use in Beijing 1991-2004 (He et al. 2006)

The rapid population growth in the last fifteen years or so has lead to major challenges for the Beijing municipality in terms of providing sufficient accommodation and infrastructure. On the one hand, the compactness and density of the central city has increased. On the other hand, Beijing has experienced a fast process of urban sprawl (Lei 2007). Wanting to reduce the population pressure downtown, the Beijing Municipal Government has encouraged development of multi-centres of the city and thus stimulated to the process of sprawling (Liu et al. 2007). Figure 2-2 illustrates the changes in land use and the sprawling of the urban city from 1991 to 2004 (He et al. 2006). Large mountainous areas in the northwest limit the potential of cultivation and urban sprawling. Of Beijing's total area of 16410.5 km^2, only about 38% is suitable for agriculture or urban settlement (Lei 2007).

Since the early 1990s, there has been a dramatic shift in how people in Beijing find and pay for their housing. In the old housing system housing was controlled and organised by the state, who assigned residents to their living units based on seniority and rank. Today, housing is to a large extent just another market commodity and it is common for residents to own their own living quarters (Li et al. 2007).

2.2 Consumption

Although China remains poor by OECD standards and pockets of extreme poverty still exist (IEA 2007), there has been a tremendous growth in the Chinese economy in the last three decades. China's real gross domestic product has grown at an average annual rate of 9.8% in the time period 1980-2006. No other large country has sustained such a growth rate for such a long period (IEA 2007). In the last two years the growth has accelerated, with gross domestic product increasing with 11.4% from 2006 to 2007[1] (NBS 2008). While the economic policy before 1978 emphasised on industrialisation through physical capital formation at the expense of consumption, growth in consumption has been a major policy objective after 1978. As a result, the last three decades have seen a rapid growth in consumption levels as well as major changes in consumption patterns (Chow 2002). Consumption level and patterns are dealt with in turn in Sections 2.2.1 and 2.2.2.

2.2.1 Consumption level

Shown in Figure 2-3 are the urban and rural expenditure levels for China and Beijing, respectively, from 1995 to 2006 (BMBS 1996-2007; NBS 1996-2007). The figure indicates that rural households have not been able to keep up with the rapid expenditure growth in urban areas. At the national level, the expenditure growth of rural households has been larger than that of urban households if the growth is measured in percentage terms. However, as the rural households started from a lower level, the gap between rural and urban households has increased. Beijing rural households have experienced about the same percentage growth as the China urban households, both more than doubling their total expenditure level in 10 years. It should be noted that the numbers in Figure 2-3 are in annual prices. The figure masks differences in price levels over time across regions, and hence fails to fully describe changes in purchasing power over time.

Figure 2-4 shows annual living expenditures in urban Beijing (in fixed 2005 prices) for five income quintiles (BMBS 1996-2007). It is evident from Figure 2-4 that gap between the well-off and the poor within urban Beijing has widened.

[1] Preliminary results

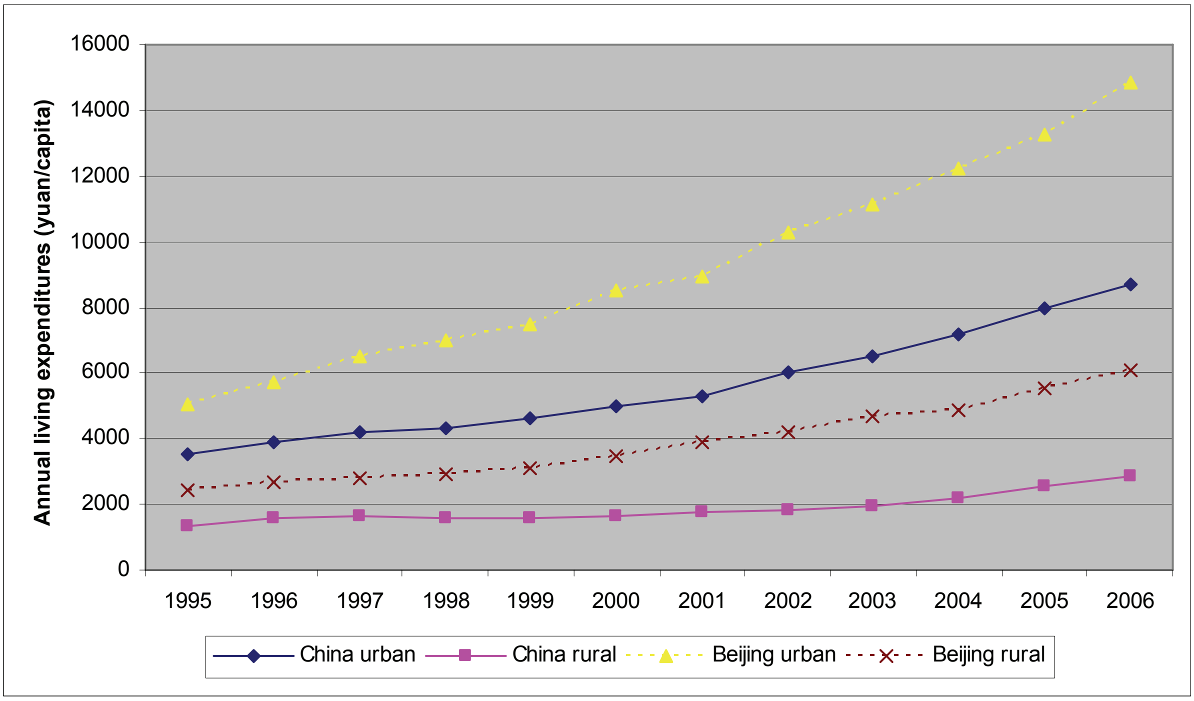

Figure 2-3: Annual living expenditures (yuan/capita) (annual prices) for urban and rural populations 1995-2006 (BMBS 1996-2007; NBS 1996-2007)

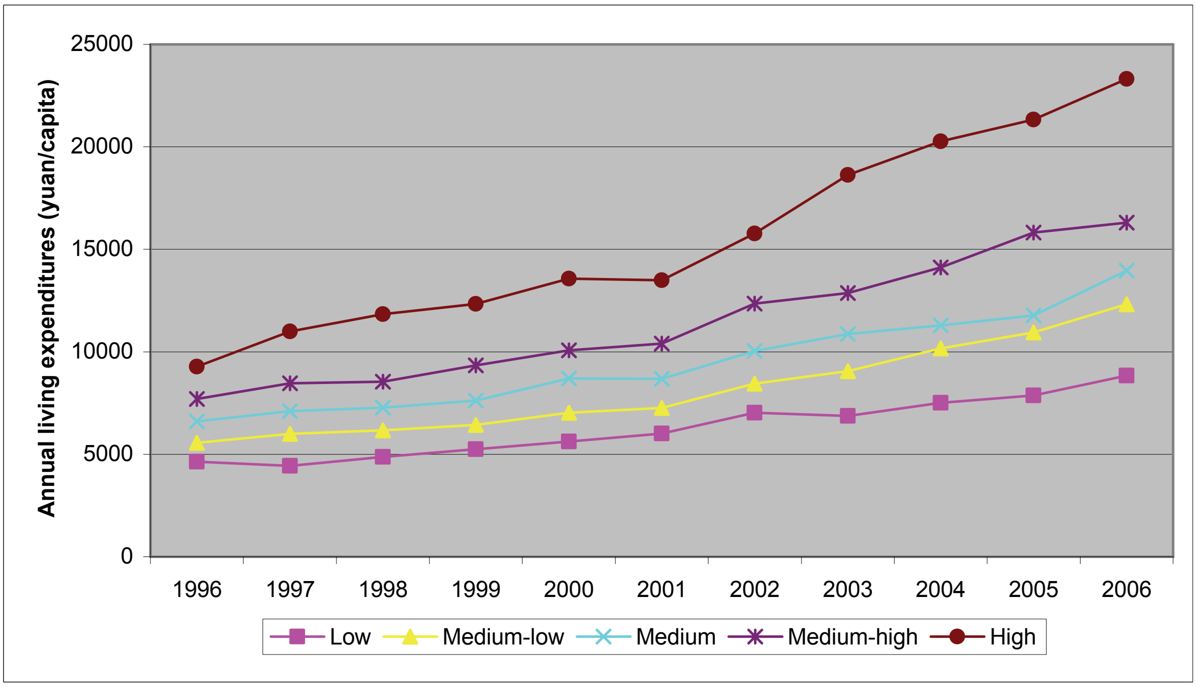

Figure 2-4: Annual living expenditures (yuan/capita) in urban Beijing by socioeconomic group 1996-2006 (fixed 2005 prices) (BMBS 1996-2007; NBS 1996-2007)

The floating population in Beijing is not included in the Beijing SCE, and thus are not represented in Figures 2-3 and 2-4. In 2006, the average annual per capita income in the floating population in Beijing was 1452 yuan (Zhai et al. 2007). By comparison, in 2006 the average income of the registered population in Beijing was 19978 yuan/capita for urban households and 8620 yuan/capita for rural households. The average income of the 20% poorest households (low income quintile) in the urban, permanent population was 9798 yuan/capita, while the 20% poorest rural households had an average income of 3275 yuan/capita (BMBS 2007).

2.2.2 Consumption patterns

Expenditure on food is dominating the household budgets in China, constituting 36.7% and 45.5%, respectively, of the total urban and rural expenditures in 2005 (NBS 2006b). In the 19th century, the statistician and economist Ernst Engel postulated the empirical law that as income rise the proportion of income spent on food declines (Chow 2002). In Figure 2-5 the national average of the Engel coefficient, i.e. the proportion of income or expenditure spent on food, is compared with the Beijing average (BMBS 2007; NBS 2007). For Chinese households, the Engel coefficient declined significantly in the latter half of the 1990s. In the recent years however, the Engel coefficient has declined at a much slower rate, particularly for urban households. As would be expected due to the significantly higher incomes of Beijing households, the Engel coefficient of Beijing households is significantly lower than for the average China household. Interestingly, the Engel coefficient of urban Beijing households has decreased at about the same rate and at about the same levels as rural Beijing households from 1995 to 2005, despite the increasing gap in total expenditure level in the same time period. A higher growth rate in relative food prices in urban areas of Beijing than in rural areas may explain this trend, although this has not been investigated.

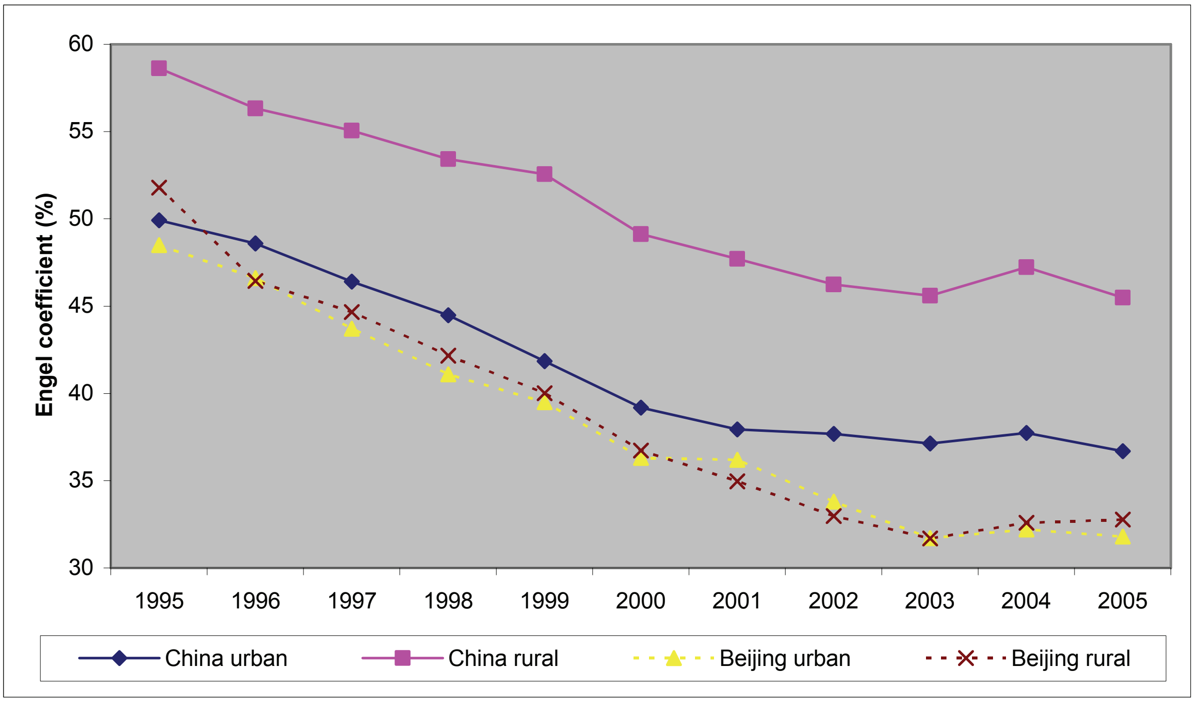

Figure 2-5: Engel coefficients (%) in urban and rural households 1995-2005 (BMBS 2007; NBS 2007)

Figures 2-6 and 2-7 illustrate, for urban and rural households respectively, how expenditure patterns in China have changed from 1995 to 2005 (NBS 1996-2007). Expenditure on food is excluded from the figures. For Chinese urban households, 'Education, cultural and recreational services' is the second largest expenditure category, increasing its share from 8.8% to 13.8% in the time period 1995-2005. One striking trend for the urban households is the rapid increase in expenditures on 'Transport and communications', constituting only 4.8% in 1995 but reaching 12.6% in 2005. The share spent on 'Health Care and Medical Services' has also increased from 1995 to 2005, while the share spent on 'Clothing' has decreased. For Chinese rural households, 'Residence' is the second largest expenditure category, its share staying rather constant since 1995 at about 14%. As for urban households, rural households' share of expenditures spent on transport and communication has increased dramatically.

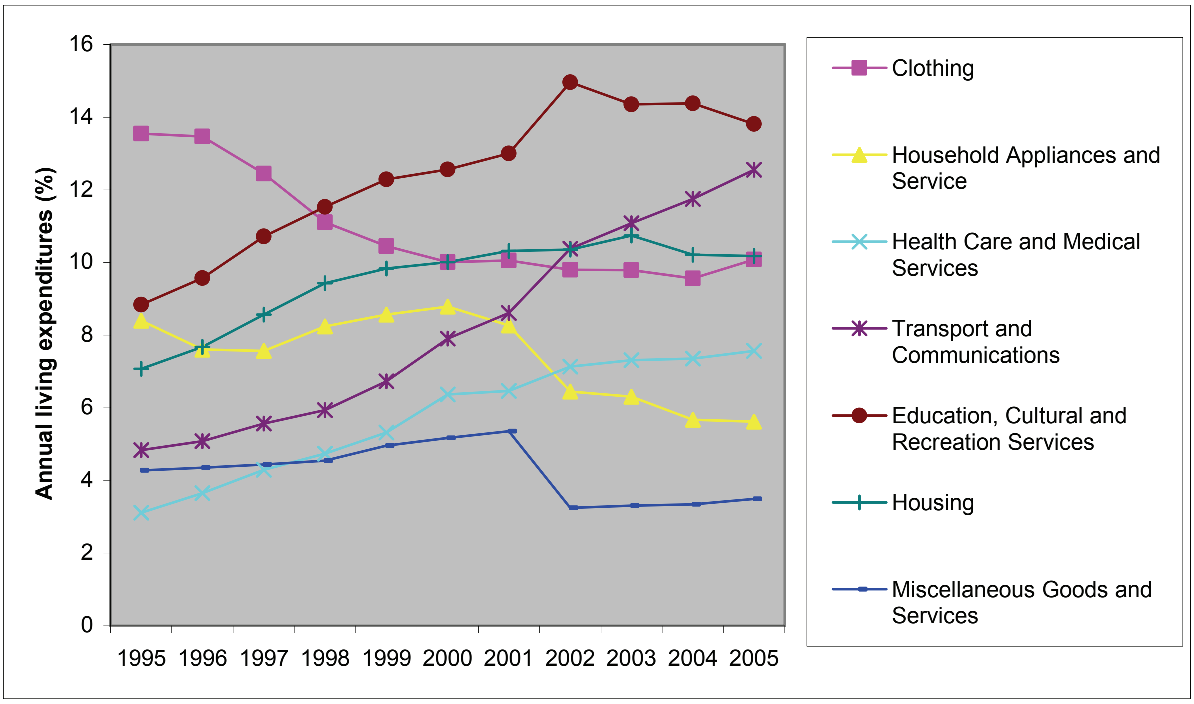

Figure 2-6: Annual living expenditures (%) in urban China by main consumption categories 1995-2005 (NBS 1996-2007)

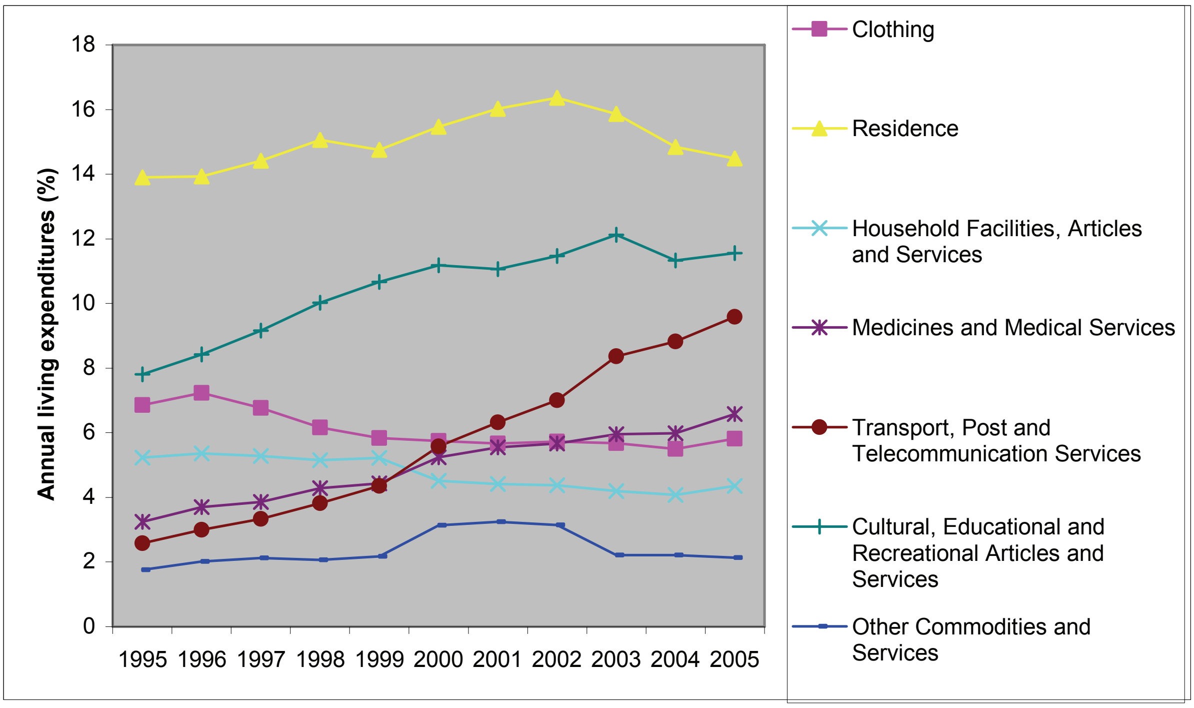

Figure 2-7: Annual living expenditures (%) in rural China by main consumption categories 1995-2005 (NBS 1996-2007)

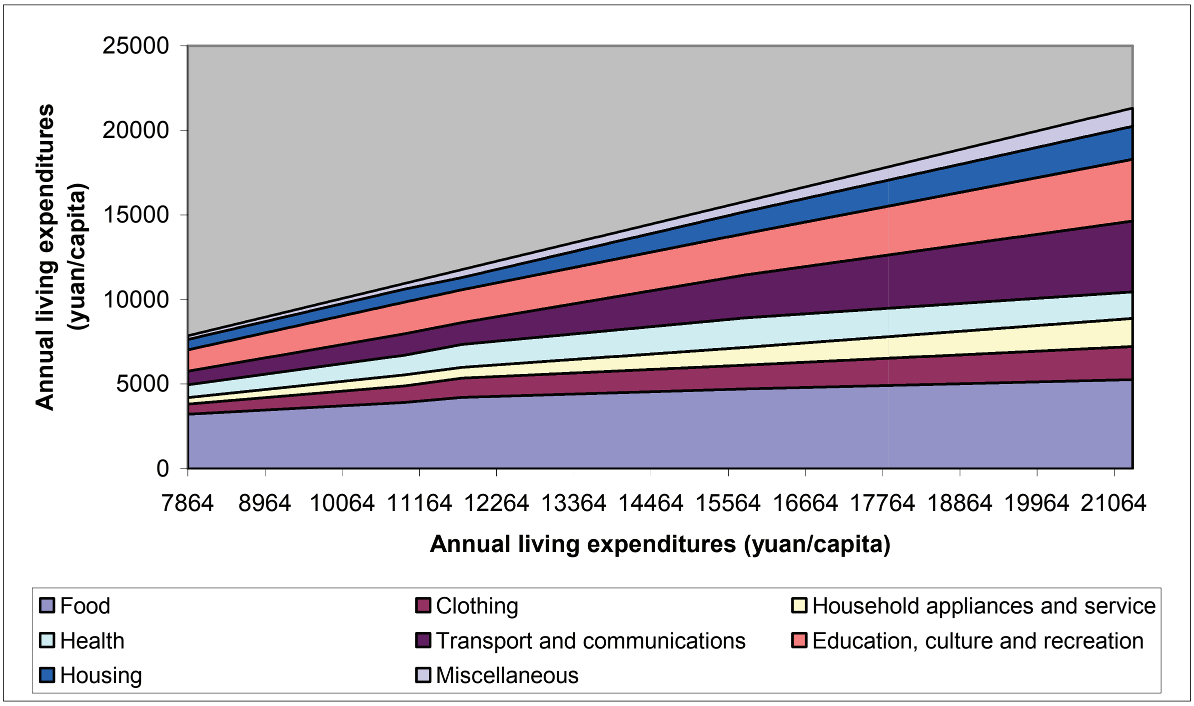

Figure 2-8: Annual living expenditures (yuan/capita) by main consumption categories versus total expenditure level (yuan/capita) in urban Beijing (BMBS 2006)

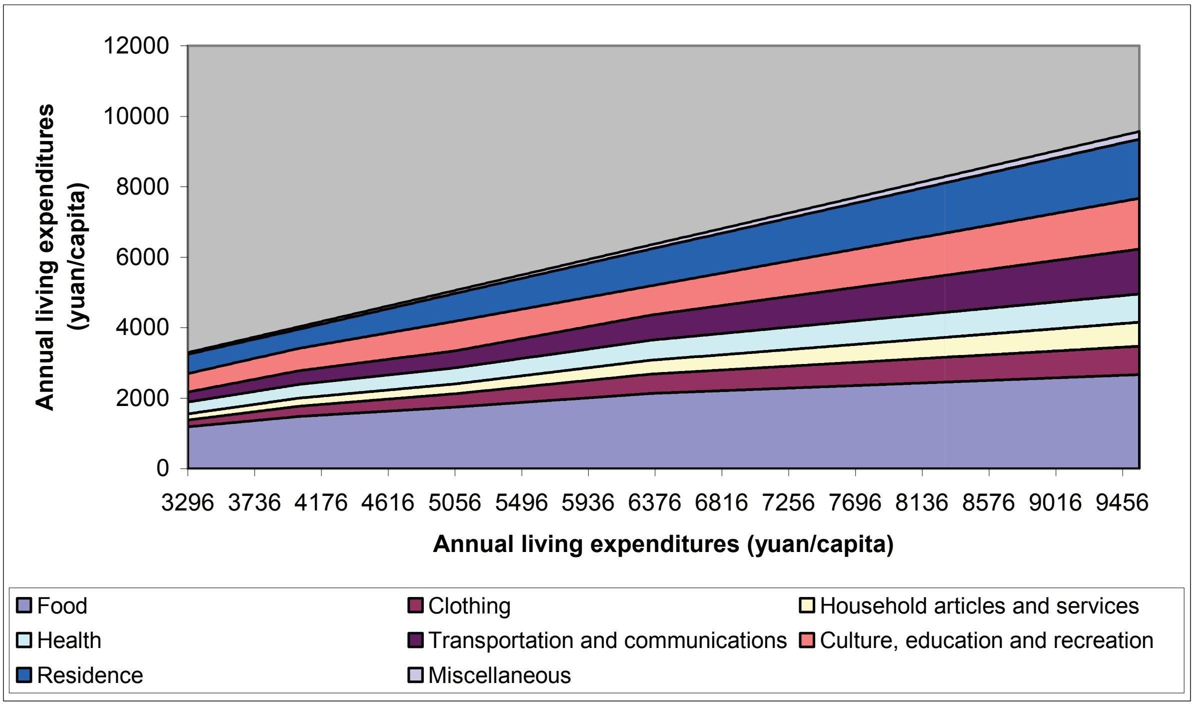

Figure 2-9: Annual living expenditures (yuan/capita) by main consumption categories versus total expenditure level (yuan/capita) in rural Beijing (BMBS 2006)

Figures 2-8 and 2-9 show, for urban and rural households respectively, annual living expenditures by main categories versus total expenditure level in 2005 (BMBS 2006)[2]. On average, food is by far the largest expenditure category, holding more than 30% both in urban

[2] Each of the figures was produced using separate data for five income quintiles. Linear interpolation was used to establish intermediate values (i.e. variations within income groups).

and rural households. There is a clear negative relationship between household income level and Engel coefficient. Although expenditure on food increases with rising income, it increases less in percentage terms than the total expenditure level. For urban households, the Engel coefficient is 40.9% for the low-income group and 24.7% for the high-income group. Similarly, for rural households the Engel coefficient decreases 36.0% at the lower end of the income scale to 27.9% at the upper end. Both for urban and rural households, 'Transport and communications' is the single expenditure category with the largest increase, in percentage terms. In urban households, expenditures for 'Transport and communications' are almost twice as large for the high-income households as for the low-income households.

2.3 Personal mobility

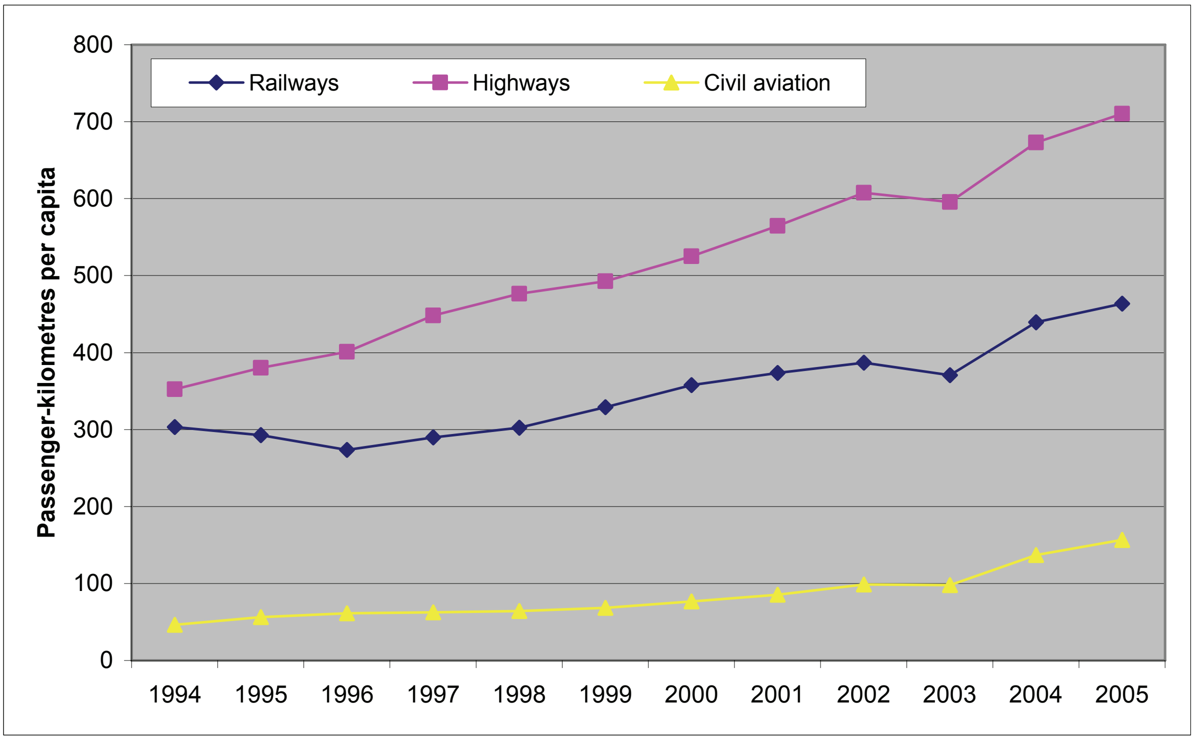

Figure 2-10: Annual per capita passenger-kilometres in China by transport mode 1994-2005 (NBS 2006b)

In China, there has been a rapid growth in personal mobility in recent years, as indicated by Figure 2-10 (NBS 2006b). This is not surprising, taking into account the increase in personal income in the same period and the high levels of personal mobility enjoyed by citizens in already developed countries. Figure 2-10 does not include intra-city and intra-rural travel. By making assumptions on usage patterns, Zhou et al. (2007) estimated that for 2002, total motorised road transport in China amounted to about 2300 passenger-kilometres, equivalent to an average annual increase of 18% since 1991. For personal cars, the average annual travel distance increased from about 17100 km in 1991 to 19300 km in 2000 (Zhou et al. 2007).

Beijing has long been known for its citizens' widespread use of bicycles. In recent years however, increases in people's income combined with relaxing restrictions on private vehicle ownership have allowed for a dramatic growth in the private vehicle stock to occur (Liu et al. 2007). Bicycle ownership on the other hand, has decreased, from 2.4 per urban household in 1995 to 1.9 in 2005 (NBS 2006b). Unfortunately, the numbers for private vehicles in Beijing, as provided by the Beijing Statistical Yearbooks, have some ambiguity to them. This will be further discussed in Section 3.3.1. Results from two surveys on private travel in Beijing, for the years 1986 and 2000, respectively, are shown in Figure 2-11 (Liu et al. 2007). The share of trips using bicycle has decreased, while the share of car trips has increased dramatically.

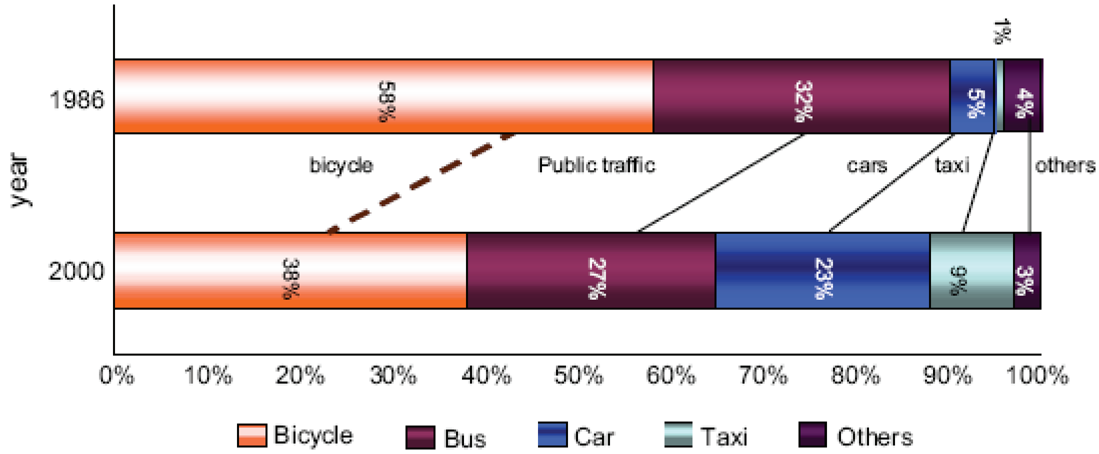

Figure 2-11: Private transport mode (%) for Beijing for 1986 and 2000 (Liu et al. 2007)

After being awarded the 2008 Olympics in 2001, Beijing has been subject to major restructurings, including improvements in road infrastructure and constructions of new subway and light railway lines. Also, a new terminal building has been constructed at Beijing's Capital Airport. From the year-end of 2000 to 2006 the number of operating subway vehicles in Beijing increased from 587 to 967. From 2000 to 2005[3], the number of passengers carried with subway increased from 0.44 billion to 0.68 billion. Similarly, the number of passengers carried with buses and trolley buses increased from 3.6 to 4.5 billion, while the number of passenger trips by civil aviation increased more than threefold from 9.3 million to 31.4 million (BMBS 2006).

In a national perspective, there are large regional differences in car ownership. Urban households in Beijing own almost five times as many vehicles as the national urban average (NBS 2006b). At least in part, regional differences in car ownership can be attributed to different local policies (IEA 2007). Although Shanghai is the wealthiest region of China, its vehicle ownership per urban household is only 27.0% compared to Beijing (NBS 2006b), reflecting policies that restrict the number of driving licenses and promote public transport (IEA 2007). There is a clear relationship between personal income and car ownership. In urban China, the lowest income households (first decile) own only 0.3 vehicles per 100 households, while for medium income households (third quintile) and the highest income households (tenth decile) the numbers are 1.7 and 16.2, respectively (NBS 2006b).

In rural areas in China, small 3-wheel or 4-wheel vehicles manufactured by Chinese domestic companies are common. In 2002, more than 3 million of such vehicles were produced in China, three times that of conventional cars. The Chinese 'rural vehicles' are smaller and slower than conventional cars and have simpler technology. Little is known about the magnitude of energy consumption and pollution associated with these vehicles, although according to one estimate for the year 2000, the diesel consumption of the Chinese rural vehicles could amount to as much as ¼ of the total diesel consumption in China. In the official statistics, the Chinese rural vehicles are regarded as farm machinery and not

[3] Passenger transportation volume of 2006 cannot be directly compared with that of 2005 due to differences in ticketing practices.

automobiles. Due to pollution and safety concerns, in many cities the vehicles are banned from intercity roads (Sperling et al. 2005).

2.4 Use of direct energy in households

The use of direct energy in households includes electricity, heat and various fuels that are burned in the household. How energy is used in different households, what types of energy that are used and what the purposes of the energy use are, are discussed in Section 2.4.1. Section 2.4.2 also concerns itself with types and purposes of direct energy use, focusing particularly on ownership of electrical appliances. Trends in household size and floor space are the topic of Section 2.4.3.

2.4.1 Direct energy use in households by end-use and type

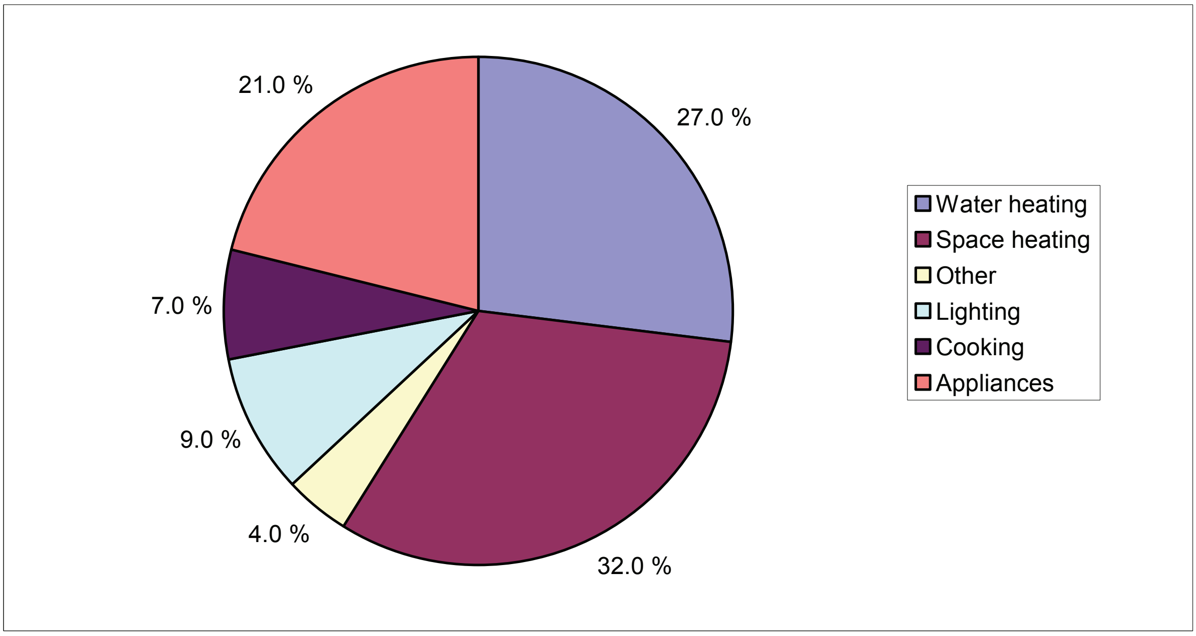

Figure 2-12: Residential energy consumption in China in 2000 by end use (%) (excluding biomass) (Zhou et al. 2007)

To the author's knowledge, relatively few studies exist that estimates household energy use in China or Beijing by different end-uses. Performing a bottom-up analysis of energy consumption in China, Zhou et al. (2007) estimates the residential energy consumption in China in 2000 by different end-uses (Figure 2-12). According to the results of Zhou et al. (2007), heating is a major energy-using activity, with space heating and water heating constituting 32% and 27% of the total energy use, respectively. Buildings that are centrally heated are found to consume almost twice as much energy as those heated by small room heaters. The third largest share of the total residential energy use is hold by appliances, constituting 21%. This category includes air conditioners, refrigerators, clothes washers and televisions. Lighting and cooking represents 9% and 7% of the total energy use, respectively.

Many households in China, mainly in rural and peri-urban areas, still rely on simple coal stoves for space heating, water heating and cooking (Aunan et al. 2006; Zhou et al. 2007). In the more developed urban areas it is more common with district heating and natural gas networks that supply households with energy for heating and cooking. According to the Beijing SCE, in 2005 91.3% of the urban households in Beijing were connected to a central heating system. The number of households in Beijing connected to the public pipeline gas network more than doubled from 1995 to 2005, reaching 0.46 million in 2005 (BMBS 2006), thus serving 82.1% of the population. Liquefied petroleum gas (LPG) is a major source for water heating and cooking in areas not served by piped gas (Brockett et al. 2002; Zhou et al. 2007), and LPG cooking stoves are popular in relatively well-off families in rural areas (Xiaohua and Zhenmin 2003). Kerosene is still used for lighting in some rural households (Zhou et al. 2007), but in recent years the residential consumption of kerosene has decreased (NBS 2006a). Electricity is rarely used for heating in Chinese households, and as electricity is not particularly suited to the methods of Chinese cooking, electricity is not the main fuel for cooking (Brockett et al. 2002). Electrical rice cookers are common, though, and an increasing number of households own microwave ovens (NBS 2006b).

An energy consumption survey for China for 1999 has been performed by Brockett et al. (2002). The survey covered 251 urban households in five Chinese cities, of which 51 households were located in Beijing. No measurements were made, but estimates of energy use were made on the basis of equipment power, self-reported usage data and actual billings. To make the samples representative the households were chosen by the China National Bureau of Statistics using the same criteria as when choosing households for the Beijing SCE. However, the small sample size constrain generalisation of the results. According to the survey results and calculations for urban Beijing, electricity accounts for 38% of the total energy use, while coal, pipeline gas and liquefied petroleum gas accounts for 35%, 20% and 7%, respectively. With only one exception, Brockett et al. (2002) found that the use of coal was restricted to households not connected to a district heating grid.

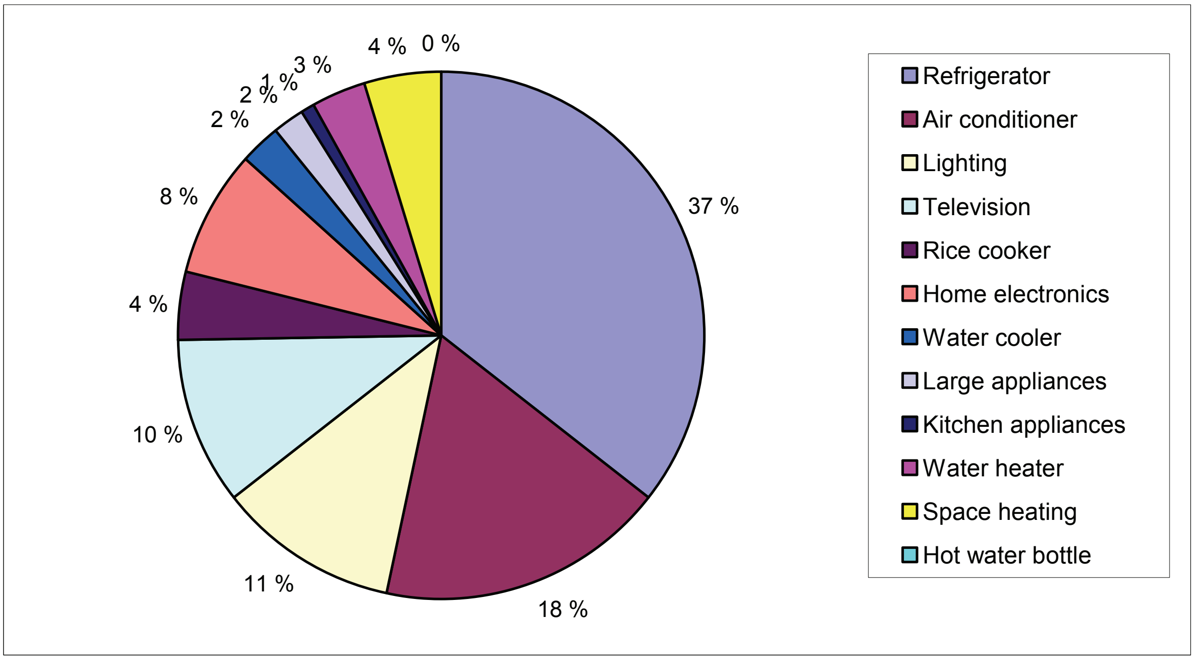

Figure 2-13: Composition of household electricity consumption in urban Beijing in 1999 (%) (Brockett et al. 2002)

Figure 2-13 shows the electricity consumption associated with different appliances, as estimated by Brockett et al. (2002). According to these estimates, the four major appliances in terms of electricity use are refrigerator (37%), air conditioner (18%), lighting (11%) and television (10%).

Biomass is excluded in the results presented in Figure 2-12. However, in rural areas in China, biomass remains the dominant source for household fuels. Generally, rural households can harvest locally available biomass energy sources free of charge (Xiaohua and Zhenmin 2003). Biomass is mostly used for space heating and cooking (Xiaohua and Zhenmin 2005; Zhou et al. 2007). According to the estimates of Zhou et al. (2007) for the year 2000, biomass represents 85% of the energy use for space heating in rural China. Due to the high consumption of biomass, rural households on average consume more energy than urban households (Zhou et al. 2007). It should be noted though that what is being compared here is theoretical energy. Utilisation of biomass for energy purposes in rural areas generally has a significantly lower degree of efficiency than utilisation of commercial energy in urban areas (Wei et al. 2001; Xiaohua and Zhenmin 2005).

Measured in theoretical energy, the most important type of biomass is straws and stalks, representing approximately 145.8 million tce[4] in China and 0.6 million tce in Beijing in 2004. Firewood represents 120.4 million tce in China and 0.2 million tce in Beijing, while biogas plays a minor role (NBS 2006a). In recent years, improvements in living standards in rural areas have been accompanied by substitution of lower quality energy sources, such as biomass and coal, with higher quality ones, mainly electricity and LPG. Large proportion of commercial energy to total energy use has been identified as a major characteristic of comparatively high-income households in rural China (Xiaohua and Zhenmin 2003). Xiaohua and Zhenmin (2005) found that Beijing rural households have a larger portion of commercial energy in the total, effective heat consumption[5] than the rural national average. For 1998, the proportion was estimated to 66% for Beijing and 44% for China.

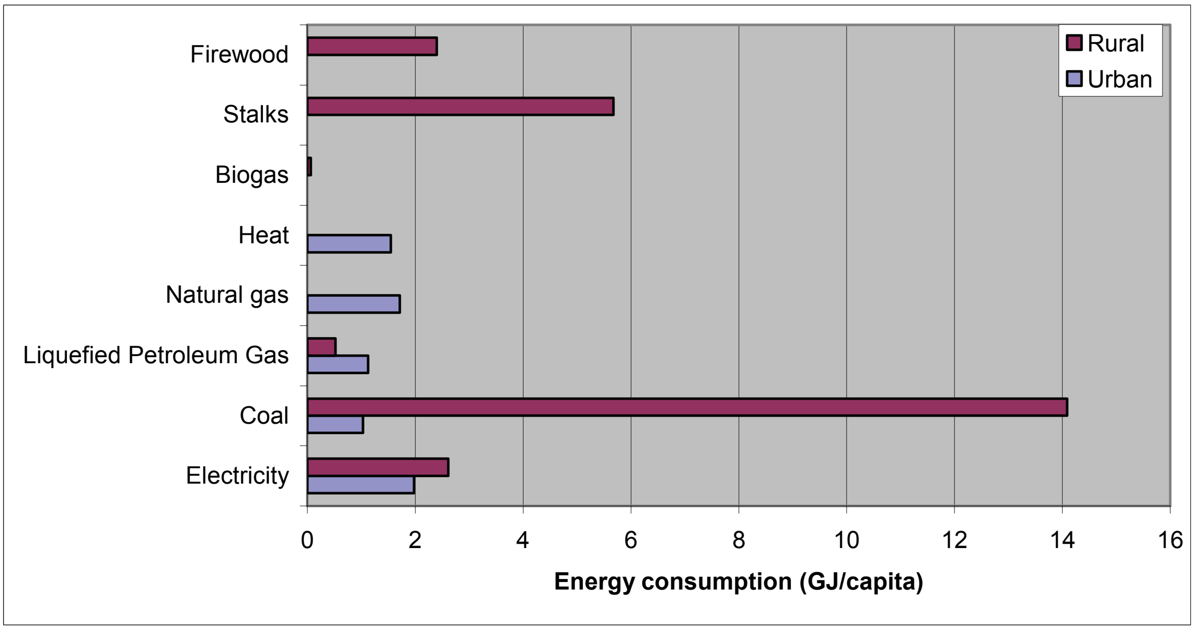

Figure 2-14: Annual direct energy use (GJ/capita) in Beijing households by type of energy (BMBS 2006; NBS 2006a)

[4] Tons of coal equivalent
[5] Sum of various effective heat energy used for cooking, heating, boiling pig food, etc

Estimates of residential consumption of various household fuels in Beijing are available in the official statistics. Shown in Figure 2-14 is the residential consumption of household fuels, electricity and heat in Beijing for the year 2005 (BMBS 2006), together with estimates of the residential consumption of biomass for the year 2004 (NBS 2006a). The numbers have been converted from coal equivalent units to GJ/capita. The numbers presented in Figure 2-14 will be further evaluated and discussed in later parts of this report.

2.4.2 Ownership of electrical appliances

Figures 2-15 and 2-16 show the ownership of some electrical appliances in urban and rural households, respectively, from 1985 to 2005 (NBS 1996-2007). In urban areas, clothes washer ownership is approaching saturation. Refrigerator ownership continues to grow, although at a much slower rate than in the late 1980s and early 90s. Due to many households owning more than one television, the average ownership continues to grow. In rural areas, television, refrigeration and clothes washer ownership lags behind the ownership in urban areas, and shows no signs of saturation. Worth noticing is the remarkable growth in air conditioner ownership in urban areas in the recent years. Owned by very few households in the early 1990s, in 2005 the residential air conditioner stock numbered more than 80 units per 100 household in urban Beijing. Presumably due to higher personal incomes, Beijing urban households in general own more appliances than the national urban average. While 100 urban households in China on average own 134.8 colour televisions, 90.7 refrigerators, 95.5 clothes washers and 80.7 air conditioners, the corresponding numbers for Beijing urban households are 152.8, 104.0, 105.0 and 146.5. Similarly, rural Beijing households also own more durable goods than the rural national average (NBS 2006b).

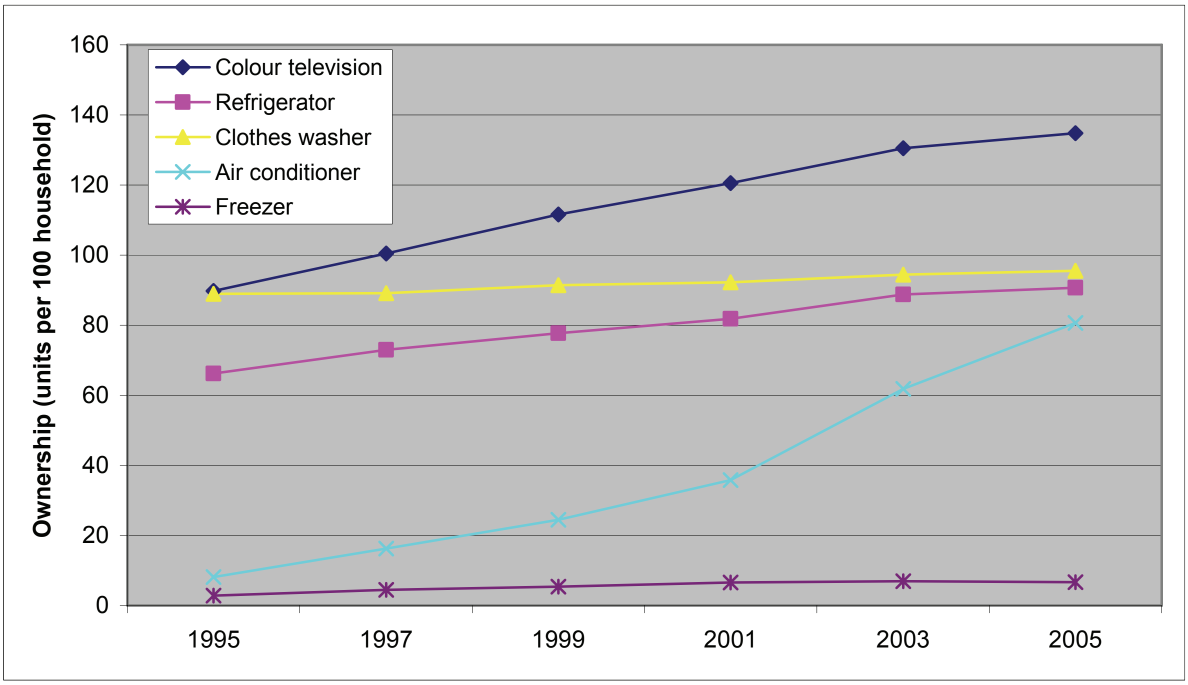

Figure 2-15: Ownership of electrical appliances (units per 100 households) in urban China 1995-2005 (NBS 1996-2007)

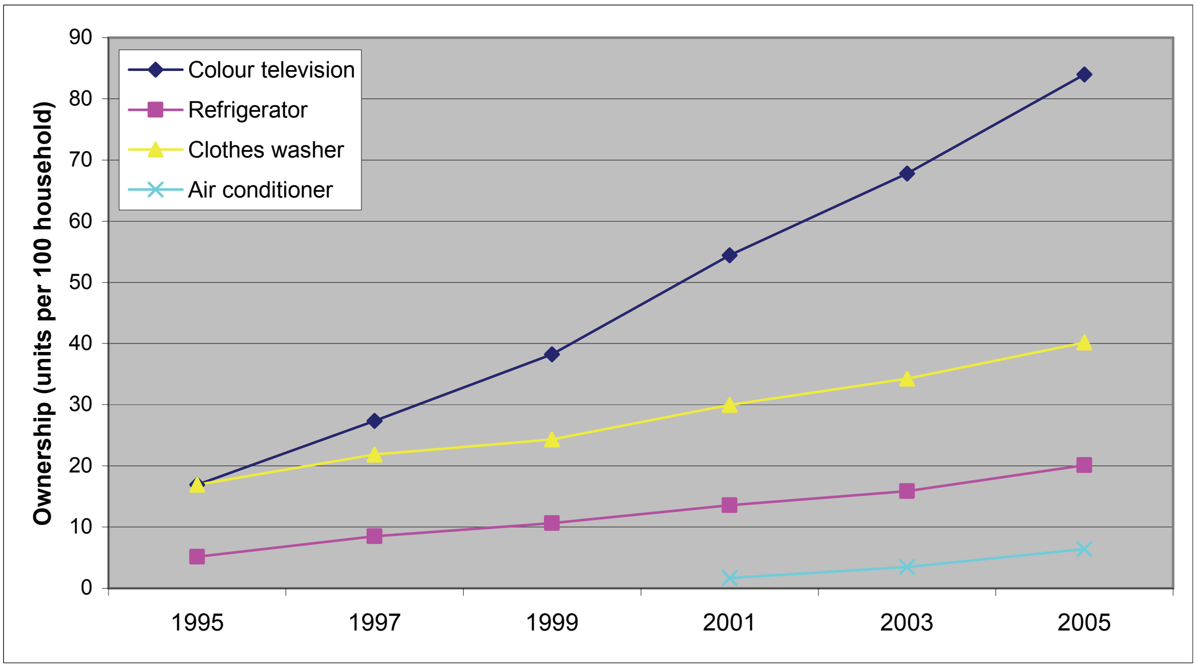

Figure 2-16: Ownership of electrical appliances (yuan/capita) in rural China 1995-2005 (NBS 1996-2007)

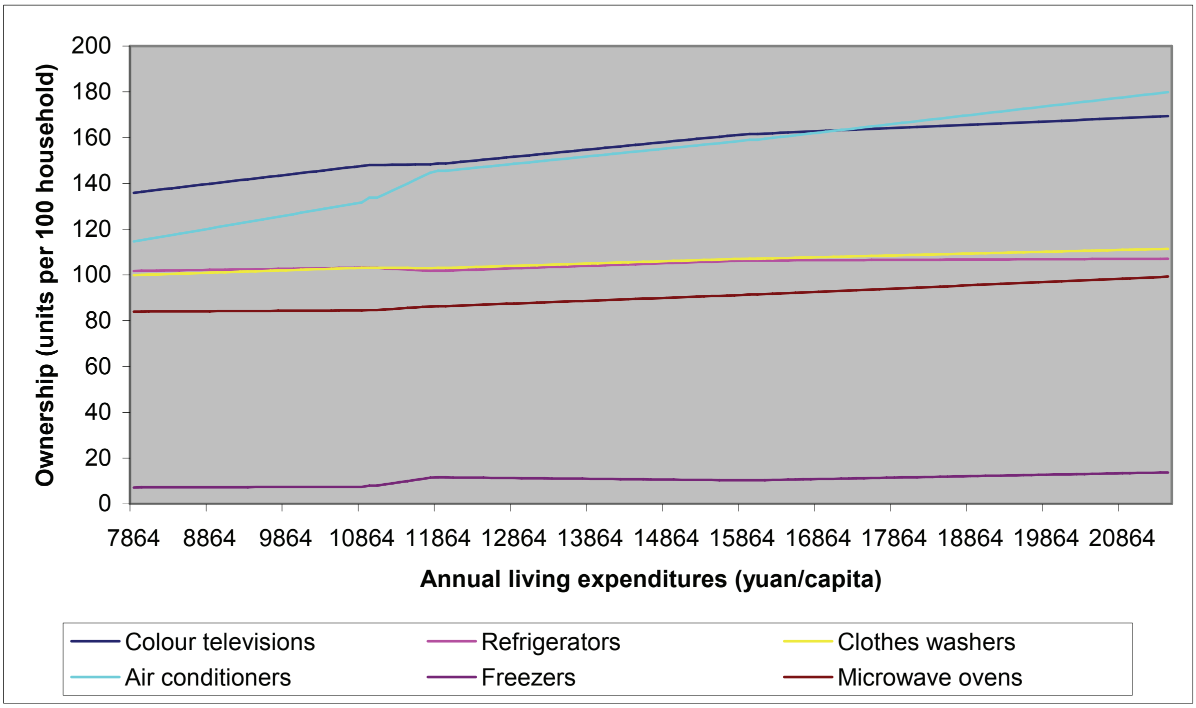

Figure 2-17: Ownership of electrical appliances (units per 100 households) in urban Beijing by annual total expenditure level (yuan/capita) (BMBS 2006)

Figures 2-17 and 2-18 show, for Beijing urban and rural households, respectively, the ownership of some selected electrical appliances by level of total living expenditures[6] (BMBS 2006). Figure 2-17 indicates that there is little potential for growth in clothes washers and refrigerators ownership in urban Beijing households, as the ownerships seem to have reached saturation. Ownership of colour television sets, microwave ovens and freezers are also rather

[6] Each of the figures was produced using separate data for five income quintiles. Linear interpolation was used to establish intermediate values (i.e. variations within income groups).

stable. Both in urban and rural households, air conditioner ownership is increasing significantly with rising income.

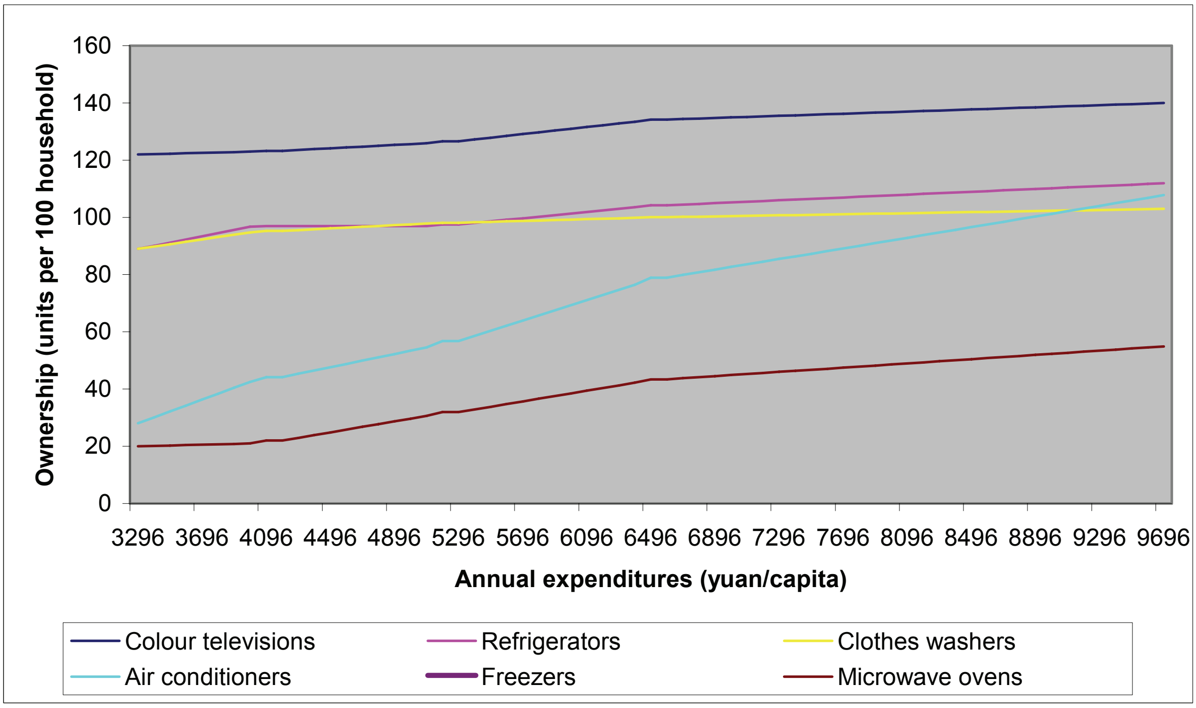

Figure 2-18: Ownership of electrical appliances (units per 100 households) in rural Beijing by annual total expenditure level (yuan/capita) (BMBS 2006)

2.4.3 Household size and floor space

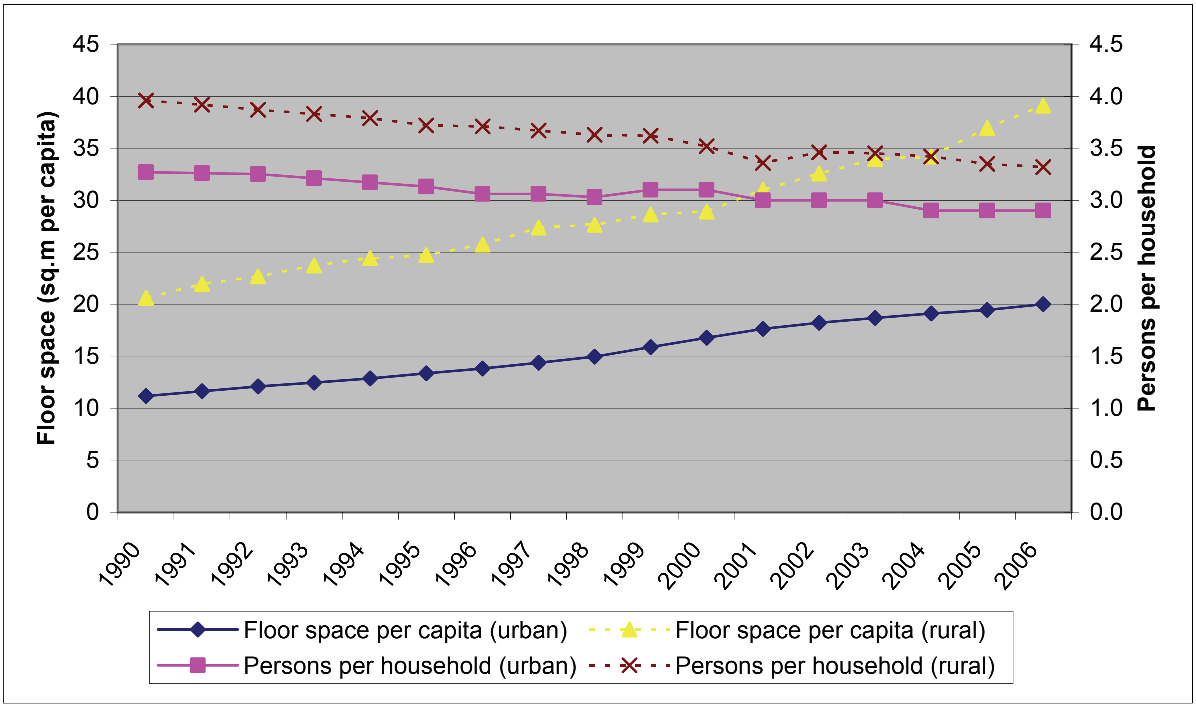

Figure 2-19: Floor space per capita (left vertical axis) and average household size (right vertical axis) in Beijing 1990-2006 (BMBS 2007)

As is shown in Figure 2-19, the average size of urban households in Beijing has decreased from 3.3 in 1990 to 2.9 in 2006. In the same time period, the size of rural households has decreased from 4.0 to 3.3. The gradual decrease in household size has been accompanied by a gradual increase in the floor space per capita. Both for urban and rural households, floor space per capita increased almost twofold from 1990 to 2006. It is worth noting that The Beijing Statistical Yearbooks provide information on ’using space’ or ’usable space’ for urban households, while for rural households the term ’living space’ is used (BMBS 2007). It is not evident if these terms are directly comparable.

There is a clear tendency that household size decreases with income. In urban Beijing in 2005, the average size of the lowest income households (first quintile) was 3.2 persons, while for the medium (third quintile) and high income (fourth quintile) households the size was 2.9 and 2.7 persons, respectively. A similar negative relationship between household size and income is also found in rural Beijing (see Tables A-1 and A-2) (BMBS 2006).

Changes in household size and floor space per person will affect the per capita energy use. A small household may possess many of the same appliances as a larger household and use approximately the same amount of energy for heating and cooling. Hence, a decrease in the average household size will contribute to an increase in the per capita energy use. An increase in floor space per capita will contribute to an increase in the per capita energy use, as larger floor space will increase the need for heating and cooling. Obviously, trends in household size and floor space per capita are linked, as a change in the household size will influence the value for the floor space per capita. In a survey of household electricity consumption in Beijing, persons in two-persons households were found to consume almost twice (1.9 times) the amount of energy as persons in four-persons households (Liu et al. 2005).

According to the analysis of Peters et al. (2006a) of the indirect household energy consumption (HEC) in China, decreasing household size contributed to a 16% increase in the HEC of urban households and 10% of rural households in the time period 1995-2004. The influence of decreasing household size on indirect HEC was found to be comparable to the impacts of population growth and changing consumption pattern, but of much less significance than urbanisation and growth in consumption level.

3 Methodology

This chapter concerns the assumptions that were made and the methodology that was used in estimating household energy consumption (HEC) today and in the near future. Evaluating how the HEC varies across income groups is a key part of the analysis. In the Beijing Survey of Consumer Expenditure (SCE), and throughout the present study, separate data are presented for five income quintiles, with each income quintile making up 20% of the households. Supplementary data on the characteristics of the five income quintiles (i.e. socioeconomic groups) are given in Appendix A. The socioeconomic groups are denoted as follows: L: Low income; ML: Medium-low income; M: Medium income; MH Medium-high income; H: High income. T denotes 'Total', i.e. the average across all income groups.

The questions of which population groups that were to be included in the calculations, and which population groups the final results are representative for, are dealt with in Section 3.1. The methodology for estimating direct HEC and indirect HEC of Beijing households today are presented in turn in Sections 3.2 and 3.3, while energy projections for the near future is the topic of Section 3.4. When working with the present study, the author spent six weeks in Beijing at the Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, collecting data and observing and experiencing life in Beijing. When writing the present report, it was considered appropriate to give a brief account of some of the observations regarding energy use and lifestyle that the author made during the stay, even though such an account would inevitably be subjective and thus not fit the norm for scientific report writing. This account is given in Section 3.5. The reasoning behind placing this section in the chapter presenting the methodology of the study, is that even if the observations cannot be directly linked with the actual calculations of HEC, they helped the author understand life and how energy is used in Beijing, and provided the author with insights that were of great value when making assumptions and interpreting the final results.

3.1 Inclusion and exclusion of population groups

Some aspects related to population numbers and trends were presented in Section 2.1. Deciding which population groups that are to be assessed, and evaluating which population groups the final results are representative for, is vital for a good analysis of HEC. When converting between numbers measured in absolute units (e.g. PJ) and numbers measured on a per-capita basis (e.g. GJ/capita), it is essential that appropriate population numbers are used. Sections 3.1.1 and 3.1.2 deal with two principally different divisions of the Beijing population, respectively. While the division of the population into urban and rural sub-populations is the topic of Section 3.1.1, Section 3.1.2 discusses Beijing's floating population and implications of the existence of this population group on the present analysis.

3.1.1 Urban and rural households

There is no doubt that there are big differences in social and economic conditions and lifestyles between rural and urban households. Due to differences in important household characteristics such as income, energy requirements of rural and urban households should be analysed separately. Numerous studies of energy use in China have shown that there are substantial differences between rural and urban areas with regards to energy consumption patterns and levels (e.g. IEA (2007), Peters et al. (2006a), Wei et al. (2007) and Zhou et al. (2007)).

For the analysis presented in the present paper, there was a question of whether rural households should be included in the calculations. It was not clear from the beginning whether the task should be to assess urban Beijing households per se, or all households located within the official Beijing city boundaries. While including both rural and urban households would make the assessment more complete, it would also make the task more complicated and increase the work load. Besides, rural households make up a relatively small share of the total population in Beijing compared to the relatively large rural share in China on average. Hence it can be argued that analysing rural households is less important when having a Beijing perspective than when looking at the whole of China.

In addition to the enhanced completeness, an advantage of including rural households would be the possibility of analysing the effects of urbanisation. The trend of a gradual and ongoing transformation of rural areas into urban areas make the distinction between rural and urban areas more blurry (Section 2.1) and hence reduce the rationale for omitting rural households from the analysis. An inclusion of rural households would call for an assessment also of non-commercial energy use.

In the end, the choice was made to include rural households in parts of the analysis. Estimates of HEC today was made both for urban and rural households. To a large extent, common sources of information and a common methodology could be applied in estimating the HEC of today of both urban and rural households. However, due to poorer data quality, the estimates of rural households' energy requirements are less accurate than that of urban households, as will be further discussed in subsequent sections of this paper. Primarily due to the higher uncertainty, rural households were excluded from the estimations of future energy use.

3.1.2 Floating population

The existence of a relatively large floating population in Beijing poses several challenges to the analysis. On the one hand, it can be argued that energy provision to the floating population is an issue that deserves serious attention, considering that a large portion of this population group suffer from low incomes and presumably are not connected to any central heating or pipeline gas supply. In an environmental perspective, burning of coal and LPG in households belonging to the floating population may be important. On the other hand, investigating the energy requirements of the floating population is made difficult by the lack of information available. The author has not succeeded in finding quantitative data on energy use in the floating population. The Beijing SCE, which provides essential inputs to the estimation of indirect energy requirements (accounted for in Sections 3.2.1 and 3.2.2), does not include the floating population. As the households belonging to the floating population disproportionally constitute the lower end of the income distribution in urban Beijing, the estimates of per capita indirect energy use will be representative for the permanent population only, and not give a realistic picture of the overall situation in urban Beijing.

Due to lack of data, the choice was made to exclude the floating population from the calculations. Finding out exactly how to exclude the floating population was problematic, though. Information in the official statistics on residential (direct) consumption of fuels, heat and electricity are important inputs to the analysis. However, it is not clear exactly how the official figures are obtained. In addition to relying on sales reports from utilities and energy marketers, the figures may be informed by consumer surveys as well as other sources (Sinton and Fridley 2001). To what extent the figures include consumption of the floating population is unknown. For the present analysis the assumption is made that the figures on residential consumption of energy is representative for the permanent population. Thus, consumption of fuels and electricity in the floating population is assumed either to be negligible or not be included in the official figures.

3.2 Estimating indirect household energy consumption

Environmental input-output analysis is a widely used method for investigating how energy requirements in the society relate to consumer purchases of goods and services. This study applies environmental input-output analysis to estimate the indirect energy consumption associated with Beijing consumption. In Section 3.2.1, a brief presentation of the theoretical background for input-output analysis is given. The concrete input-output model that was used to estimate the household energy requirements of Beijing consumption is described in Section 3.2.2. A brief account of some other input-output based studies having a China focus is given in Section 3.2.3.

3.2.1 Theoretical background of input-output analysis

Input-output analysis is a theoretical framework and an applied economic tool that was developed by Professor Wassily Leontief in the late 1930s. The fundamental purpose of economic input-output analysis is to analyse the relations between sectors in an economy. In later works, the input-output framework has been extended to deal more explicitly with energy consumption and environmental pollution (Miller and Blair 1985; UN 1999). The total energy requirements or emissions associated with delivering goods or services to final consumers can be calculated combining economic input-output tables with direct energy requirement or pollution data by industry sectors.

To develop an input-output model, the economy which is analysed must be divisible into a number of sectors. The model can be constructed from observed data concerning the flows of products from each of the sectors (as a producer) to each of the sectors (as a purchaser). There is in principle no restriction on the choice of units, hence each flow can be measured in either physical or monetary units, and the flows are not required to be measured in the same units. In its most basic form, an input-output model consists of a system of linear equations, each one describing the distribution of an industry's product throughout the economy. One fundamental assumption in the input-output model is that the inputs used in producing a product are related to the industry output by a fixed coefficient (Miller and Blair 1985; UN 1999). In environmental input-output analysis, it is assumed that, for all sectors, the energy requirements associated with the delivery of goods to final consumption is proportional with the total production. Similarly, the amount of pollution, for instance CO_2, can be calculated by assuming that the emissions associated with delivering goods to final consumption is proportional with the total production (Wilting 1996).

The mathematical structure of a basic input-output model is given e.g. in Miller and Blair (1985). In the input-output model, the total output of an economic sector, X_i, is set equal to the sum of all the inter-industry sales of sector *i* and its sales to final demand:

$$X_i = z_{i1} + z_{i2} + ... + z_{in} + Y_i \qquad 3.1$$

The *z* terms represent the sales by sector *i* to the other sectors in the economy, whereas Y_i is sector *i*'s sales to final demand. *n* is the number of economic sectors. Equation 3.1 represents the distribution of sector i's output. Defining one equation similar to Equation 3.1 for each of the sectors, the entire economy can be expressed as a series of *n* equations representing the distribution of each sector's output.

$$\begin{aligned} X_1 &= z_{11} + z_{12} + ... + z_{1n} + Y_1 \\ X_2 &= z_{21} + z_{22} + ... + z_{2n} + Y_2 \\ &\vdots \\ X_n &= z_{n1} + z_{n2} + ... + z_{nn} + Y_n \end{aligned} \qquad 3.2$$

Z_{ij} is the flow from sector *i* to sector *j*. The direct requirement coefficient, a_{ij}, is defined as the ratio of sector *j*'s input supplied by sector *i* to the total output of sector *j*.

$$a_{ij} = \frac{z_{ij}}{X_j} \qquad 3.3$$

a_{ij} can thus be interpreted as the input *i* (product of sector *i*) used in the production of one unit of output of industry *j*. Replacing each *z* term in Equation 3.2 by $a_{ij}X_j$ gives:

$$\begin{aligned} X_1 &= a_{11}X_1 + a_{12}X_2 + ... + a_{1n}X_n + Y_1 \\ X_2 &= a_{21}X_1 + a_{22}X_2 + ... + a_{2n}X_n + Y_2 \\ &\vdots \\ X_n &= a_{n1}X_1 + a_{n2}X_2 + ... + a_{nn}X_n + Y_n \end{aligned} \qquad 3.4$$

Grouping all *X* terms to the left and introducing matrix notation:

$$(I - A)X = Y \qquad 3.5$$

where *I* is the *n* by *n* identity matrix (containing ones in the diagonal elements and zeros elsewhere), A is a matrix containing all the direct requirement coefficients (a_{ij}), *X* is a column vector containing each sector's total output and *Y* is a column vector containing each sector's deliveries to final consumption.

If the final demand of each sector is known, the total output of each sector necessary to deliver this demand can by calculated by:

$$X = (I - A)^{-1}Y \qquad 3.6$$

In environmental input-output analysis, information on the direct emissions or energy requirements by industry sectors, *F*, is needed. The environmental impact associated with delivering the final demand, *E*, can then by calculated by:

$$E = FX \quad 3.7$$

One major strength of environmental input-output analysis as a tool is the complete coverage of the complex network of inter-linked operations in an economy. Input-output analysis provides an opportunity to consider all inputs in the whole life-cycle of a product. However, high aggregation level of the data may lead to uncertainties and limit the usefulness of input-output analysis in policy making. While traditional energy input-output analysis can provide a good view of the energy requirements or pollution associated with the average household consumption, providing a breakdown into main consumption categories, it does not offer opportunities for observing more detailed changes in consumption (Hertwich 2005; Wilting 1996).

There are also other challenges and limitations that need to be resolved. Many studies assume domestic energy and emissions intensities for imported products, which may result in significant errors (Hertwich 2005). Explicitly taking regional technology differences into account, Reinvang and Peters (2008) find that the majority of CO_2 emissions in Norwegian consumption are embodied in imports. As both Vringer and Blok (1995) and Hertwich (2005) point out, another shortcoming is that it is possible that input-output based studies overestimate the positive correlation between energy requirement and income. If high income households systematically purchase products that cost more per physical unit, such as more expensive organic food or designer clothing, this will not be reflected in the results. Moreover, the treatment of capital in the present analyses is unsatisfying. Either, capital formation ('investments') is treated as a final demand category, rather than allocated to the goods production that the investments support. Or, a steady state economy is assumed, meaning that investments in the current economic cycle are used as a proxy for the investments required to support consumption in the current economic cycle (Hertwich 2005). The larger the economy, the less problematic the steady-state assumption is.

3.2.2 Input-output model for Beijing

Chinese input-output tables are compiled by the Chinese National Bureau of Statistics (NBS) every five years. The tables used in this study are from the year 2002, which is the most recent data available. There are 122 industry sectors in the 2002 input-output data. The data was organised and prepared for use by Dr Glen Peters at the Industrial Ecology Programme, Norwegian University of Science and Technology. Standard procedures (Miller and Blair 1985; UN 1999) were used to normalise the input-output tables.

A construction of Chinese energy and pollution (CO_2, SO_2, NO_x) data suitable for environmental input-output analysis is described in Peters et al. (2006b), and the data is available online. The input-output calculations presented in the present paper are based on this data. In addition, the data basis for the calculations in the present paper contains two modifications made by Dr Glen Peters and colleagues that are not included in the online material. The first modification concerns the total consumption of coal in China, which according to the official statistics decreased substantially from 1996 to 2000, after having risen steadily since 1980. In 2000 the trend was reversed, with the coal consumption increasing rapidly between 2000 and 2004. The dip in coal consumption is depicted in Figure 3-1 (Peters et al. 2007). The accuracy of the underlying data has been questioned. The results of Akimoto et al. (2006), who used observational satellite data for tropospheric NO_2 to verify coal consumption data, indicate that there was significant under-reporting of coal in the period 1996-2002. The modification Dr Glen Peters and colleagues made was to scale the coal consumption upwards to match the trend-line from 1980 to 1996 (Figure 3-1) (Peters et al. 2007).

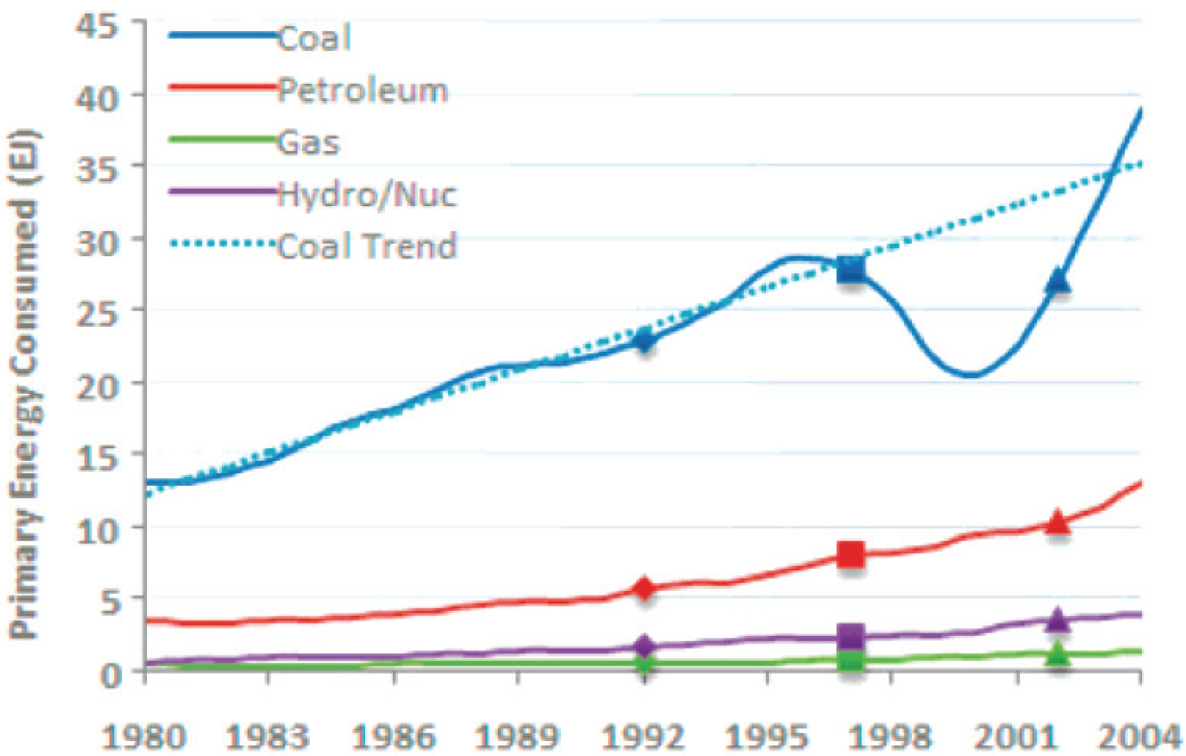

Figure 3-1: Historical energy consumption (EJ) in China 1980-2004. The dashed line shows the linear trend in coal consumption from 1980 to 1996 (Peters et al. 2007)

The second modification concerns some disadvantageous aggregation in the original NBS energy statistics, where transport services are aggregated together with postal, storage and telecommunications services. This aggregation is problematic due to the large difference in energy intensity of the two industries. Assumptions were made to disaggregate the original, aggregated industry sector and to shift postal, storage and telecommunications services into the sector 'Others' (which is generally service based industries). The two modifications are accounted for in more detail in the supporting material for Peters et al. (2007).

Input-output based studies of household environmental impact typically use data from consumer expenditure surveys to obtain the final demand *Y*. The content of the surveys typically include expenditure patterns for different income groups, as well as information on other household characteristics (Hertwich 2005). As has been mentioned previously, for China, such data is gathered in the Chinese Survey of Consumer Expenditure (SCE) and is available in the annual statistics publication China Statistical Yearbook. The survey samples more than 50 000 urban households and 68 000 rural households throughout the country (NBS 2006b). Specific data for Beijing households is presented in the separate, annual publication Beijing Statistical Yearbook. The present study uses data from the 2005 Beijing SCE, which is based on a sample of 2000 urban households and 3000 rural households. In the Beijing Statistical Yearbook, data from the urban and rural surveys are presented separately.

Living expenditures are divided into 77 categories for urban households and 23 categories for rural households. The population are divided into five groups according to their income, each group representing 20% of the households sampled in the urban and rural surveys, respectively. Separate expenditure data is presented for each of the socioeconomic groups (BMBS 2006).

Inflation is accounted for by converting the 2005 expenditure data to 2002 prices, using the Beijing consumer price index. In all other aspects, it was assumed that the national input-output tables and industry energy data for 2002 are representative for Beijing in 2005. Furthermore, it was assumed that imports are produced using domestic technology. Capital formation, of which construction constitute 78% (Peters et al. 2007), was treated as a final demand category. Trade and transport margins were not adjusted for, and hence some expenditure may be misallocated.

To calculate the HEC it is necessary to either aggregate the input-output data to match the categories in the Beijing expenditure survey, or to disaggregate the expenditure data and map it to the different input-output industry sectors. To avoid losing information contained in the input-output data, the latter alternative was chosen. After loading the inter-industry coefficient matrix (*A)* , the energy and pollution data (*F*) and the expenditure data (*Y*), the model calculates the energy requirements using Equations 3.6 and 3.6 (in Equation 3.7, the final demand vector *Y* is diagonalised to get the energy impact associated with each sector). The results, initially broken down into 122 industry sectors, are then redistributed to the original expenditure categories, i.e. 77 categories for the calculations of urban households and 23 categories for rural households.

Beijing has an extensive public central heating network. It is not entirely clear if the consumption of heat is included in the results from the input-output calculations. The question is whether expenses on public central heating are included in the expenditure survey. Explicit information on this matter has not been found. It was assumed that for households who are connected to the municipal central heating network, central heating is regarded as a public service. Hence it can be assumed that the public central heating is either not paid for the households, or the payments are regarded as a tax and excluded from the living expenditures in the survey. Under this assumption the energy used to supply the public central heating network will not be included in the results. Expenses on heat deliveries from smaller, privately owned central heating systems are included in the living expenditures.

Electricity consumption is included in the results from the input-output calculations. However, in the present analysis, households' consumption of electricity is estimated separately (Section 3.3.2). To avoid double counting, a modification is made to the input-output model to remove the direct electricity consumption. The estimates of indirect energy consumption associated with delivering electricity to households are not subtracted.

3.2.3 Other studies

Traditionally, most of the input-output based studies of HEC have focused on consumption in developed countries. Input-output based studies focusing explicitly on Chinese consumption are relatively few in numbers. Wei et al. (2007) assessed both direct and indirect environmental impact of Chinese households, but did not use input-output tables in the analysis. An input-output based analysis of how indirect HEC varies with household characteristics is presented in Peters et al. (2006a). For the year 2002, total HEC was estimated to 21GJ/p for urban households and 5GJ/p for rural households (excluding biomass). Consumption volume was found to be the dominant factor contributing to increased indirect HEC between 1995 and 2004 (Peters et al. 2006a). In another study, Liang et al. (2007) used a multi-regional input-output model to perform a scenario analysis on China's future energy requirements, dividing the country into eight economic regions.

In the recent years, several studies evaluating the energy and pollution embodied in international trade have had a focus on environmental impacts occurring in developing countries. For example, Reinvang and Peters (2008) found that in 2006, 45% (18 Mt) of the CO_2 emissions embodied in Norwegian consumption occurred in developing countries. The emissions occurring in China almost tripled from 2.4 Mt in 2001 to 6.8 Mt in 2006 (Reinvang and Peters 2008). In the case of the U.S., the results of Weber and Matthews (2007) indicate a rapid growth from 1997 to 2004 in the CO_2 emissions embodied in U.S. imports from China. According to estimates by the International Energy Agency, energy embodied in China's domestic production of goods for exports constituted 28% of the country's total energy consumption. By comparison, the energy embodied in Chinese imports constituted 12% of the Chinese energy demand (IEA 2007).

3.3 Estimating direct household energy consumption

Sections 3.3.1 to 3.3.7 concern the direct energy consumption of households and account for how numbers for direct energy consumption were established. Each section deals with one type of direct energy use, namely: fuels for transport; electricity; heat; coal; pipeline gas; liquefied petroleum gas and other fuels; and biomass. In the present analysis, establishing numbers for direct energy consumption involved two steps. Firstly, the total energy consumption in urban and rural Beijing, respectively, was determined. Secondly, the total energy consumption was distributed among socioeconomic groups.

Net calorific values (NCVs), which give information on the energy content (in energy units) of an energy source per unit mass, were used to convert physical units to energy units. Peters et al. (2006b), collecting NCVs for China from different data sources, found that the NCVs vary between data sources. In the present analysis, NCVs were used according to the final recommendations of Peters et al. (2006b). Hence, in the calculations of direct HEC the same set of NCVs were used as in the input-output model used to calculate indirect HEC.

Figures from the Beijing Statistical Yearbook provided essential inputs to the calculations of both indirect and direct energy consumption. The numbers from the Beijing Statistical Yearbooks that were used in the present analysis are primarily valid for the year 2005, except for a few numbers related to rural transport that are valid for the year 2006. This seemingly strange practice of combining figures for the year 2006 and 2005 needs to be explained. In the early phases of the work that is presented in this paper, the 2006 edition of the Beijing Statistical Yearbook, which presents numbers for the year 2005, was the most recent edition available to the author. Thus, 2005 was chosen as the reference year in the calculations. At a later phase in the work period, the author got access to the 2007 edition of the Beijing Statistical Yearbook, presenting figures valid for 2006. Considering the time constraints put on this work, it would be a too time-consuming exercise to change the reference year to 2006. However, as will be discussed in Section 3.3.1, the 2007 edition contains some numbers related to rural transport that are missing in the 2006 edition. Hence there was a need to use these numbers from the 2007 edition in the calculations, although the calculations primarily are based on numbers from the 2006 edition.

3.3.1 Fuels for transport

According to the official statistics, the urban residential transport fuel use in Beijing in 2005 was 44.6 and 2.6PJ, for gasoline and diesel oil, respectively (BMBS 2006). The Beijing Statistical Yearbooks prior to the 2007 release do not provide any information on rural residential consumption of gasoline and diesel oil. In the 2007 release however, rural residential transport fuel use for 2006 is estimated to 4.0 and 0.6 PJ, for gasoline and diesel oil, respectively (BMBS 2007). To achieve consistency in the calculations used in this study, the numbers should be for the year 2005. It is assumed that the rural residential consumption of transport fuel amounted to 4.3PJ in total in 2005. This number is obtained by taking the rural consumption of 2006 and the urban consumption of 2005 and 2006, and assuming that the per capita percentage increase in fuel consumption between 2005 and 2006 is the same for urban and rural.

It is unclear exactly how the estimates in the official statistics of residential gasoline and diesel oil consumption have been calculated. Presumably, the estimates are informed by household surveys and sales reports from utilities. Whether the gasoline and diesel oil consumption of floating population are covered is an open question, as the floating population are not included in the SCE. Anyhow, the floating population's consumption of fuel for transport is presumably minimal. It is assumed that the energy use of taxis is not included in the residential figures.

Credible and detailed information on private ownership of vehicles is limited. While the China Statistical Yearbooks give information on ownership of 'Automobiles' for urban households in a national perspective, including information on car ownership by income level, no information on car ownership is given for rural households. The Beijing Statistical Yearbook gives information on the total vehicle stock in Beijing, including separate numbers for private vehicles and private cars. However, after 2003, the Beijing Statistical Yearbooks do not present any results from the Beijing SCE regarding ownership of automobiles or cars. Estimates of the stock of civil motor vehicles in Beijing, as presented in the Beijing Statistical Yearbooks from various years, are somewhat ambiguous. According to these statistics, the number of private vehicles in Beijing has increased from near zero in the mid-80s to 1.54 million in 2005. Of the private vehicle stock in 2005, 990 000 were private cars, according to the Beijing Statistical Yearbook of 2006. However, in the Beijing Statistical Yearbook of 2007 the terms are changed. Here, the stock of private cars in Beijing in 2005 is said to be 1.54 million, while 990 000 is said to be the number of private sedans. According to investigations by Zhou et al. (2007), numbers for private vehicle stock in China also includes mini-buses and most of the taxis.

The available data on private ownership of motor vehicles in Beijing was considered insufficient to provide a basis for distributing the transport fuel consumption among socioeconomic groups. Instead, data from the Beijing SCE was used. For urban households, the expenditure category 'Transport fuels' were used as a basis for mapping the gasoline and diesel consumption to the different income groups. Unfortunately, the Beijing SCE for rural households does not specify how much rural households spend on transport fuels. In lack of better alternatives, the aggregated expenditure category 'Transport' is used for distributing transport fuel consumption among rural households. Although it is not evident exactly what kind of expenditures are accounted for in this category, it is clear that it does not cover expenditure on means of transport (which is another, separate category). It cannot be ruled out that the some expenditures on transport fuel falls within the category ‘Transportation and communications’, which holds a large share of the total expenditures on transportation and communications. This is a source of uncertainty.

3.3.2 Electricity

The energy balance for Beijing, as is provided in the Beijing Statistical Yearbooks, includes estimates of the residential electricity consumption. In 2005, the residential electricity consumption in Beijing was 25.4PJ and 6.6PJ for urban and rural areas, respectively (BMBS 2006). It is not clear exactly how these estimates have been obtained. As for gasoline and diesel oil, it unclear to what extent the consumption of the floating population is included, but the average consumption of a resident belonging to the floating population is presumably small compared to the average permanent resident. It seems plausible to assume that the estimates of electricity consumption found in the official statistics have a higher certainty to them than estimates of e.g. coal consumption. As opposed to the difficult to follow supply of coal, utilities delivering electricity have monopoly and thus one would expect that the consumption can be tracked with greater accuracy. However, according the official numbers the electricity consumption in urban and rural areas is about the same, when measured on a per capita basis. This seems implausible in the light of the significant higher ownership levels of electrical appliances in urban areas (Section 2.4.2). Use of older and less efficient appliances in rural households compared to urban households may partly explain the relatively high electricity consumption in rural areas.

Alternatively to using the official estimates, residential electricity consumption can be calculated by combining assumptions on unit energy consumption with data on ownership of electrical appliances. In addition to the appliances included in Figures 2-17 and 2-18, the Beijing consumer surveys provide information on ownership of e.g. electrical fans, microwave ovens, personal computers and vacuum cleaners. The data for urban households are more detailed than that of rural households. Adopting numbers for the average unit energy consumption (kWh/year) of refrigerators, clothes washers, colour TVs and air conditioners from Zhou et al. (2007), and multiplying these values with ownership levels (BMBS 2006), it was found that the total electricity consumption associated with these appliances is 1.7GJ/capita and 1.0GJ/capita in urban and rural households, respectively. By comparison, the official estimates of residential electricity consumption (25.4PJ in urban and 6.6PJ in rural areas) are equivalent to 2.7GJ/capita in both urban and rural households. According the 1999 survey of Brockett et al. (2002), refrigerators, colour TVs and air conditioners together accounted for 65% of the total electricity consumption in urban Beijing households.

For establishing the total residential electricity consumption, it was considered more sensible to use the estimates provided by the official statistics, than to calculate the total electricity consumption in a separate, bottom-up estimation. Although the relatively high electricity consumption in rural households may seem unlikely, there are no obvious reasons for why the official numbers for residential electricity consumption would be erroneous. Refrigerators, colour TVs and air conditioners constitute a large portion of the residential electricity consumption (Brockett et al. 2002; Zhou et al. 2007). To cover the electricity consumption not associated with these appliances, a relatively large number of less energy-intensive appliances would need to be considered as candidates for further investigation. The energy consumption associated with a specific appliance is dependent not only on the efficiency, but also on the usage pattern. An assessment of efficiency and usage pattern of a relatively large number of appliances could turn into a laborious task and would inevitably be burdened with uncertainty.

For distributing the electricity consumption among socioeconomic groups, two approaches were combined. The Beijing Statistical Yearbook provides information from consumer surveys on ownership of some selected appliances by level of income. Again adopting numbers for the average unit energy consumption (kWh/year) of refrigerators, clothes washers, colour TVs and air conditioners from Zhou et al. (2007), estimates of the electricity consumption associated with these appliances was obtained for each socioeconomic group. These estimates, covering the energy use of four electrical appliances, cover 82.6% of the urban electricity consumption and 38.4% of the rural, when comparing with the official numbers of residential electricity consumption. Data on living expenditures from the Beijing SCE was used as a basis for distributing the residual electricity consumption among socioeconomic groups. For urban households, the expenditure category 'Electricity' served as a basis, while for rural households, in lack of better alternatives, the category 'Other residence' was used. Unfortunately, for rural households the living expenditures on residence and housing is divided into three sub-categories only. The exact expenditures on electricity are unknown.

3.3.3 Heat

Beijing has an extensive coal-fired central heating network. In 2000, 1.71 million tons of coal was burned to supply the city's heating network with energy. By 2008, the number has been projected to increase to 2.40 million tons (Ma et al. 2004). A number for the total residential consumption of heat is provided in the energy balance for Beijing, as is found in the Beijing Statistical Yearbook. For 2005, the urban residential consumption of heat was 19.9PJ (BMBS 2006), equivalent to 2.2GJ/capita. There is no rural consumption of heat (BMBS 2006).

As was discussed in Section 3.2.2, it is not entirely clear whether residential energy use of public central heating is included in the results from the input-output calculations. For the present analysis it was assumed that the input-output calculations do not cover public central heating. An estimate of total residential consumption of heat was obtained from the official statistics. It is important to note that this estimate does not include any life-cycle evaluations of heat supply, and thus some of the indirect energy requirements associated with delivering the heat are excluded from the calculations.

The author has not succeeded in finding information on how the consumption of heat varies with income. Presumably, floor space is an important factor when evaluating the consumption of heat. However, data on how floor space varies between income levels is not available. In lack of better alternatives, data on household size by income level is used as a basis for distributing the heat consumption among socioeconomic groups. For example, it is assumed that households with three household members have 50% higher per capita heat consumption than households with two household members.

3.3.4 Coal

The most recent estimates of rural and urban residential consumption of coal in Beijing are found in the Beijing Statistical Yearbook. For the residential consumption it is distinguished between ‘Coal’ and ‘Coal products’. In energy terms, consumption of ‘Coal products’, which is limited to urban households, is of minor importance compared to the consumption of ‘Coal’. The China Energy Statistical Yearbook, also providing estimates of the rural and urban residential consumption of coal in Beijing (for the year 2004), divides the residential consumption into the categories ‘Raw coal’ and ‘Briquettes’. It seems evident that the terms ‘Raw coal’ and ‘Briquettes’ in the China Energy Statistical Yearbook are equivalent to the terms ‘Coal’ and ‘Coal products’ in the Beijing Statistical Yearbook. The numbers presented in the Beijing Statistical Yearbook is measured in units of 10 000 tons. When converting to standard energy units (PJ), it is assumed that the NCVs for ‘Raw coal’ and ‘Briquettes’ from Peters et al. (2006b) are representative for the consumption categorised as ‘Coal’ and ‘Coal products’, respectively.

As is illustrated in Figure 2-14, the per capita consumption of coal is much higher in rural Beijing households than in urban households. Due to this relatively high consumption of coal in rural households, rural households in Beijing have a higher total consumption of commercial energy than urban households, when measured on a per capita basis. Apparently, the general view in the literature that urban households generally have a higher per capita consumption of commercial energy than rural households (IEA 2007; Zhou et al. 2007) does not hold for Beijing. Indeed, in a national perspective the general view that urban households’ demand for commercial energy is higher than that of rural households is well supported by the official statistics. Simply dividing the official estimates of total residential consumption of energy in China in 2004 (NBS 2006a) with population numbers, it is found that urban residents consume more than twice the amount of commercial energy as rural residents, when measured on a per capita basis. Similar calculations reveal that while the per capita consumption of coal in 2004 was about 1.5 times higher in rural China than in urban China, in 2005 the per capita consumption of coal in rural Beijing was about 13.6 times higher than in urban Beijing.

As was noted already in Chapter 2, many characteristics of Beijing households are not representative for China. Hence it is not surprising that there are differences between Beijing and China with regards to the patterns and levels of commercial energy use. What is surprising is that the difference is so large. Why there is such a stark contrast between the Beijing and China situations when it comes to rural versus urban energy consumption has not been clarified. The large mismatch between the Beijing and China situations raises the question of whether the official estimates of coal consumption can be trusted. Undoubtedly, the official estimates of rural consumption of coal are uncertain, as there are no records for a large portion of the sales of coal to rural households. At least in part, the official estimates rely on information on output from small rural mines and survey data on coal purchases by households. As urban households often purchase coal from enterprises that keep records of sales, the urban coal consumption can be determined with greater accuracy (Sinton and Fridley 2001). Perhaps particularly for coal, the large floating population in Beijing is a source of uncertainty when estimating the per capita consumption. Considering that households belonging to the floating population generally lack access to central heating and pipeline gas, it is likely that many of these households rely on coal for energy supply. The magnitude of the floating population’s coal consumption, and to what extent this consumption is included in the official estimates of urban residential consumption, is unknown.

For the present analysis it is assumed that the official estimates of residential coal consumption are sufficiently accurate, in spite of the seemingly too high rural consumption. Attempts of developing a basis for modifying the official estimates have not been successful. With more accurate data not being available, one is left with no other choice than to trust the official estimates. Also, as was also noted in the case of electricity (Section 3.3.2), there are no obvious reasons for why the official estimates should be erroneous.

Data from the consumer expenditure surveys were used as a basis for distributing the coal consumption among socioeconomic groups. For urban households, the expenditure category 'Coal' is an obvious choice as a basis for distributing the coal consumption. For rural households, the resurging problem of highly aggregated expenditure categories brings uncertainty into the calculations. As rural households' expenditures on coal are not specified, the expenditure category 'Fuels' is used to allocate coal consumption to the different income groups.

3.3.5 Pipeline gas

The Beijing energy balance in the Beijing Statistical Yearbook includes an estimate of the amount of natural gas (in m^3) supplied to urban households through pipelines. There is no rural consumption of pipeline gas. Converted to standard energy units (PJ), the energy supplied to households through pipeline gas exceeds the amount of energy supplied trough the central heating network (Figure 2-14). The pipeline gas consumption of households belonging to the floating population is assumed to be negligible.

In the urban Beijing SCE, there is a single expenditure category for expenditures on pipeline gas. This expenditure category is used as a basis for distributing the pipeline gas consumption among socioeconomic groups.

3.3.6 Liquefied petroleum gas and other fuels

As for the energy carriers discussed in the Sections 3.3.1 to 3.3.5, estimates of urban and rural consumption of liquefied petroleum gas (LPG) can be found in the Beijing energy balance in the Beijing Statistical Yearbook (BMBS 2006). Similarly as for coal, the large floating population in Beijing is a source of uncertainty when estimating the per capita LPG consumption. Households lacking access to central heating and pipeline gas, a common situation for households belonging to the floating population, may turn to LPG for energy to cooking, heating and boiling water. Unfortunately, the magnitude of LPG consumption in the floating population, and to what extent this consumption is included in the estimate of residential LPG consumption found in the official statistics, is unknown.

Expenditures on LPG is a single category in the urban Beijing SCE. Urban consumption of LPG was distributed among socioeconomic groups in accordance with expenditures on LPG. For rural households, the expenditure category 'Fuels' was used as a basis for distributing LPG consumption among socioeconomic groups. This expenditure category was also used for distributing coal consumption, and hence the percentage distribution of rural coal consumption between socioeconomic groups will be the same as for LPG consumption.

The Beijing energy balance in the Beijing Statistical Yearbook includes an estimate of urban residential consumption of coking gas. Measured in energy units and compared with consumption e.g. coal, LPG and natural gas, the residential consumption of coking gas is small (3.8% of urban LPG consumption and 2.5% of natural gas consumption). For converting the consumption of coking gas from mass units to standard energy units (PJ), the NCV for 'Coke oven gas' was used. The expenditure category 'Others fuel' in the urban Beijing SCE was used as a basis for distributing the consumption of coking gas among socioeconomic groups.

3.3.7 Biomass

Estimates of residential consumption of biomass energy sources by province, including specific values for Beijing, are available in the China Energy Statistical Yearbook (NBS 2006a). This is not an annual publication, and the most recent estimates, covering firewood, stalks and biogas, are for the year 2004. The numbers for biomass energy in Figure 2-14 are based on these estimates. The figures of biomass consumption in the China Energy Statistical Yearbook are presented in both mass units and coal equivalent units. For the present analysis, numbers measured in coal equivalent units were used and multiplied with a conversion factor 29.308 GJ/ton coal equivalent (adopted from Peters et al. (2006b)). The per capita rural consumption of biomass was assumed to be the same in 2005 as in 2004.

Even more so than for consumption of commercial energy, figures of non-commercial energy consumption rely heavily on estimates and should only be taken as a rough guide to the magnitudes of consumption. However, stability in figures over time suggest that the statistics are consistent and reflect actual trends (Sinton and Fridley 2001).

Little information has been found on how consumption of biomass varies depending on the households' income. As households do not have to pay to harvest locally available biomass energy sources (Xiaohua and Zhenmin 2003), data from expenditure surveys cannot serve as a basis for distributing biomass consumption between socioeconomic groups. As was noted in Section 2.4.1, the portion of commercial energy in total, effective energy consumption has been found to increase with income. Rising incomes in rural areas are accompanied by a transition from traditional energy sources (such as coal and biomass) to high quality energy sources (mainly electricity and LPG). Due to the changing energy structure accompanying income growth in rural areas, the effective energy consumption increase with income, while the average theoretical energy use remain rather constant, according to one study (Xiaohua and Zhenmin 2003).

Due to limitations with regards to data availability, no attempt was made to distribute biomass consumption in Beijing among socioeconomic groups. Hence, only figures of average biomass consumption in Beijing are presented in this paper. Insights provided by e.g. Xiaohua and Zhenmin (2003, 2005), as has been discussed in Section 2.4.1 and the present section, are interesting, but considered insufficient as a basis for allocating biomass consumption in Beijing to different income groups. China's rural household energy consumption patterns and levels vary considerably between regions (Xiaohua and Zhenmin 2003, 2005), and the author lacks in-depth knowledge on living styles and biomass consumption in Beijing rural households. A further investigation of this issue has not been given high priority, mainly because rural households constitute a relatively small share of the Beijing population.

3.4 Energy projections

Although the assessment of the overall household energy use in Beijing included both urban and rural households, the energy projections are limited to urban households. It was decided not to include rural households in the projections for two main reasons. Firstly, rural households represent a relatively small share of the total households in Beijing. Moreover, the share is decreasing year by year, and it is considered likely that the downward trend will continue also in the near future. Secondly, the results for the rural households are less detailed and have a higher uncertainty to them.

The projections of urban HEC were divided into three main parts. In the first part, which is described in Section 3.4.1, it was investigated how distribution of welfare can affect the HEC. Strictly speaking, the analysis described in Section 3.4.1 is not really a projection, as it does not include an estimate of future energy use. However, it does include an alteration to the present day situation (the results for the reference year 2005), and aims at providing some insights that can be useful in evaluating future energy use. In the second main part (Section 3.4.2), the high-income households are put in a trendsetting role, and the question of what would happen if all residents should adopt the lifestyle and consumption of the high-income group is investigated. In the final part of the projection analysis, urban HEC in Beijing is projected towards 2015. The energy projections towards 2015 are described in Section 3.4.3.

The three analyses described in Sections 3.4.1 to 3.4.3 all have in common that they are based on the results for the reference year 2005 and what is known about the differences in HEC between income groups. The basic assumption is made that when populations become more affluent, they will adopt the lifestyles and consumption pattern of the populations that already enjoy the higher level of affluence. Under this assumption, future growth in the average per capita income can be thought of as populations moving from one income group to another, adopting the lifestyles of the higher level income group. For example, low income households experiencing income growth will adopt the lifestyle of the medium-low income households, while medium-low income households experiencing income growth will adopt the lifestyles of medium income households. The exact distribution of income is not known, as the official statistics divide the population into five income quintiles. The average income for each group is known, but no information is given on variations in income within the groups. In the calculations, linear interpolation is used to establish intermediate values.

Economic growth is well known to be an important driver for increased energy demand. As the results presented in Section 4.1 demonstrate, HEC increases with rising income. Due to the great importance of income in determining the HEC, projections of energy consumption will be highly sensitive to underlying assumptions about income growth. A brief discussion historical economic growth and increases in expenditure level was given in Section 2.2.1. In the coming 10-15 years, it is likely that the Chinese economy will continue to grow at substantial rates (Chow 2002; IEA 2007). In their five-year plan for the time period 2006 to 2010, the Chinese government set a target of 7.5% annual GDP growth (IEA 2007). So far, actual growth rates have by far exceeded the government's target. In the 'reference scenario' of their energy projections, IEA (2007) assumes that the Chinese economy will grow 7.7% per year between 2005 and 2015. The GDP growth is expected to slow gradually, and over the time period 2005-2030, the reference scenario assumes an average annual growth rate of 6.0%. The coastal region's economy is expected to grow more rapidly, averaging 6.1% through to 2030 (IEA 2007).

3.4.1 Distribution of wealth and energy intensity

A rather simple exercise was made to investigate how the distribution of wealth can affect energy use in Beijing. In addition to a reference scenario, representing the actual situation in the reference year 2005, two alternate scenarios were constructed. The alternate scenarios differ from the reference scenario in that the distribution of the population among the socioeconomic groups is altered. Hence, the alternate scenarios have different distributions of wealth than the reference scenario, with one scenario representing a more even distribution of wealth and the other a more uneven distribution. The average total expenditure level across all income groups was kept the same in all three scenarios. Details of the reference distribution and the two alternate distributions, together with details of a scenario introduced in Section 3.4.2, are shown in Table 3-1.

3.4.2 High-income households as trendsetters

Making the assumption that households becoming more affluent will adopt the lifestyles of the already affluent households puts the high-income households of today in a trendsetting role, and thus they become particularly interesting to study. Calculations were made to estimate the energy impacts of moving the entire urban population up in income corresponding to the high-income group of today.

Table 3-1: Share of households belonging to each socioeconomic group for four scenarios. The scenarios representing alternate distributions of wealth were presented in Section 3.4.1

	L	ML	M	MH	H
Distribution of wealth					
Even distribution of wealth	10.5 %	24.5 %	26.0 %	26.0 %	13.0 %
Reference	20.0 %	20.0 %	20.0 %	20.0 %	20.0 %
Uneven distribution of wealth	27.5 %	17.5 %	14.5 %	14.5 %	26.0 %
High-income households as trendsetters	0.0 %	0.0 %	0.0 %	0.0 %	100.0 %

While the average per capita expenditure level is kept constant for the two scenarios representing alternate distributions of wealth, attributing the lifestyle and consumption of the high-income group to the entire population implies that the average expenditure level increases with 61.0%, from 13244.2 yuan/capita to 21325.2 yuan/capita. This is equivalent to an annual per capita increase in expenditure level of 10.0% over a 5-year period (i.e. towards 2010) or 4.9% over a 10-year period.

3.4.3 Projections of energy consumption: 2005-2015

In the analyses introduced in Sections 3.4.1 and 3.4.2, information on energy use in 2005 serves as a basis for the calculations. The same data basis was used also for making energy projections towards 2015. In principal, the projections were made by making assumptions on future per capita growth in expenditure level for each of the five socioeconomic groups. The HEC for given socioeconomic group in a given year was determined according to the households' per capita expenditure level, by interpolating in the data basis for 2005. However, making the projections also required some other assumptions to be made. With future growth in expenditures, the problem arose that some households' expenditure surpasses the expenditure level of the high-income group of today. Hence, performing the calculations required information on lifestyles and consumption of ‘very high income’ households, information which was not readily available. To overcome this problem, a sixth income group, representing households with an average total expenditure level of 51000 yuan/capita, was constructed. Assumptions were made to establish the expenditure patterns and use of household fuels for the very high income group. The construction of the very high income group is accounted for in more detail in Appendix D. The author would like to stress that while the construction of the sixth income group to some extent is based on firm data and knowledge, a good portion of guesswork was also needed. By introducing the very high income group in the calculations, a new source of uncertainty is added. It is important that the results of the energy projections are interpreted in the light of the assumptions about the sixth income group, which are accounted for in Appendix D.

Table 3-2: Historical and projected average annual growth (%) in annual per capita expenditure level

	T	L	ML	M	MH	H
Historical data						
1997-2006	8.2 %	6.6 %	8.3 %	7.8 %	7.8 %	9.6 %
Scenario 1: Even distribution						
2007-2010	8.2 %	10.1 %	8.2 %	8.1 %	7.9 %	7.7 %
2011-2015	8.0 %	9.4 %	8.4 %	8.4 %	8.2 %	6.5 %
Scenario 2: Uneven distribution						
2007-2010	8.2 %	6.9 %	7.9 %	8.0 %	7.8 %	9.5 %
2011-2015	8.0 %	6.8 %	7.8 %	7.8 %	7.8 %	8.8 %

Two scenarios of future growth in total expenditure level was constructed, representing even and uneven distribution of wealth, respectively. The average growth in per capita expenditure level across the entire population is the same in both scenarios. Annual growth rates for each of the scenarios are given Table 3-2. Graphical presentations of historical and projected growth in expenditure level are given in Figures D-1 and D-2. Assumptions on future growth in total expenditure levels were primarily based on extrapolating historical trends. The assumptions on future expenditure growth were considered to be in rough accordance with assumptions on economic growth in the existing literature (see introduction to Section 3.4).

According to the latest Beijing master plan, which was formulated by the Beijing municipal government in 2004, the total population in Beijing will be limited to 18 million in 2020, with the urban population counting 16 million (Beijing Municipal Government 2005). With actual urban population numbers reaching 13.33 million in 2006, this is equivalent to an average annual growth in the urban population of 1.31% in the period 2006-2020. Making the rough assumption that the urban population will grow with 1.6% in the period 2006-2015, it is assumed that the urban population will number 15.38 million in 2015.

3.5 Field work

Staying and working six weeks in Beijing, the author benefited from access to more data and valuable human resources in the research community. Also important were the benefits gained through observations of people and energy use in Beijing. Studying relationships between lifestyles and energy use purely on the basis of statistics and literature, without basic knowledge of the everyday lives of the people one attempts to study, may result in unrealistic assumptions and interpretations being made. It would be naive to believe that a six weeks stay in a city of a foreign country, visiting only selected areas of the city and meeting a selection of people not at all representative for the entire population, can equip one with a deep understanding of the everyday life of different people in the city. However, observing life and meeting people can provide one with an understanding that, even though it may be relatively superficial, can be immensely useful compared with the case where one has to rely exclusively on written material.

Observations contributing to increased understanding of lifestyle and household energy consumption can be made in everyday situations, talking with people about everyday subjects, experiencing the road traffic or the metro rail, or experiencing local air pollution. Such everyday situations, albeit useful to the author, will not be discussed further in this report. The remainder of this section will be devoted to three excursions in Beijing. These are: 1) Visit to a lower secondary school (Section 3.5.1); 2) Two family visits (Section 3.5.2); and 3) Visit to a 'migrant village' (Section 3.5.3). The aim of these excursions was for the author to get more familiar with life in Beijing, with emphasis on aspects important in terms of HEC.

3.5.1 Lower secondary school visit

Nine pupils from lower secondary school (age 15-16), as well as two school teachers, were present at the meeting. The pupils filled out a questionnaire prepared by the author. The English version of the questionnaire is provided in Appendix E.1. The completion of the questionnaires was followed by a discussion.

Seven of the nine pupils live in households with three household members. The other two pupils live in households with five and seven household members, respectively. All the pupils live in apartments in multiple-stories buildings. Some results concerning the energy use of cooking, space heating and water heating are shown in Table 3-3. Seven out of nine households use central heating for indoor space heating, while the remaining two households use coal. Of the seven households that have access to pipeline gas, all of them use pipeline gas for cooking. The two households lacking access to pipeline gas use bottled gas for cooking. Four pupils report that in their household, pipeline gas is also used for water heating. There are seven reported cases of electricity being used for water heating. Three pupils report that they use more than one energy source for water heating, which seems unlikely. It is possible that some pupils have not distinguished between energy used to provide hot water for e.g. bathing, and electricity used to heat water for hot drinks (e.g. tea). No pupils report that they use energy sources other than the alternatives listed.

Table 3-3: Energy use by type and end-use for households in class survvey

	Cooking	Space heating	Water heating
Bottled gas	3	0	1
Gas from pipes	7	1	4
Coal	0	2	0
Electricity	2	0	7
Central heating (steam)	0	7	0
Other	0	0	0

Table 3-4 shows the ownership of durable goods in the nine households, according to the results of the survey. Five of the nine households do not own a car. The household with seven members own two cars. All households, including the household with seven members, own one refrigerator. Ownership of air conditioners ranges from zero to four per household, but all households except one own at least one air conditioner. Television sets and computers are owned by all households, clothes washers are owned by all households apart from one. Only one household owns a standalone freezer, which supports the finding that penetration of standalone freezers in urban Beijing is relatively low (Figure 2-15). Dishwashers, of which the penetration level is only 0.9 per 100 households, according to the official statistics (BMBS 2007), are owned by three of the nine households. For the three households that own a dishwasher, the pupils report that the dishwasher is used only 0-2 times a week.

Table 3-4: Ownership of durable goods (units per household) for households in class survey

Household number	1	2	3	4	5	6	7	8	9	SUM
Refrigerator	1	1	1	1	1	1	1	1	1	9
Air conditioner	4	2	2	0	3	2	2	1	1	17
Television	1	2	1	1	1	1	2	1	1	11
Clothes washer	1	1	1	0	1	2	1	1	1	9
Computer	3	2	2	1	1	1	2	1	1	14
Freezer	0	0	1	0	0	0	0	0	0	1
Electric cooking appliances	8	2	2	3	5	4	5	1	3	33
Dishwasher	1	1	0	0	1	0	0	0	0	3
Car	0	0	0	0	1	1	2	1	0	5

All nine pupils stated that they are 'very concerned' about impacts of climate change. Six pupils are 'very concerned' about local air pollution, while three pupils are 'quite concerned'. On average, the pupils are less concerned about safe energy and water supply than for climate change and local air pollution. Three pupils are 'very concerned' about safe energy supply, while two pupils are 'very concerned' about safe water supply.

All nine pupils stated that they would want their household to be able to spend more money on leisure activities. Interestingly, only one pupil (the pupil whose household had five members and owned one car) stated that he/she wished their household would spend more money on transport. Five pupils singled out food as something they would want their household to spend more money on. Similarly, four pupils singled out medical articles and services, two pupils singled out household articles and two pupils singled out clothing.

In the plenary sessions following the completion of the questionnaires, the pupils expressed strong opinions on the traffic. They all seemed to agree that the heavy traffic is a serious problem in Beijing, and that the heavy traffic in their neighbourhood is causing them a lot of inconvenience. Two of the pupils argued that the heavy road traffic made their transport to school slow and tiresome, regardless of choice of transport mode. Due to the traffic congestion, transport with car and bus is time-consuming and walking and bicycling is troublesome, they argued. Another pupil said that he used bicycle to and from school, which takes him 10 minutes, while travelling by car would take him 20 minutes. Several pupils expressed frustration on the bus system, which they regarded as unsatisfying. The pupils had many suggestions of what could be done to reduce the traffic. One pupil suggested that a school bus system, collecting and bringing school pupils to and from school, should be introduced. She reckoned that such a system is common in many other countries. According to one pupil's opinion, only those living far away from school or work should be eligible for using private car for commuting. Another pupil argued in favour of introducing a rotation system based on the numbers on the license plate, restricting specific cars from driving at specific times.

The pupils voiced concern about climate change, local air pollution and resource scarcity. Several pupils criticised the generation of their parents for having a low environmental consciousness and for being thoughtless in their behaviour. One pupil proposed that the author prepared more questionnaires and calculated the energy use of each of the pupils' households. The questionnaire was also criticised by one pupil for being 'kind of Western' and too simple. She was particularly provoked by the listing of the alternative 'single family detached' in Question 1, which she interpreted as living in a 'villa', a Western type of living unheard of in Beijing. She also commented on some electrical appliances that 'no one owns in Beijing' (e.g. standalone freezer) being listed as alternatives.

3.5.2 Households visits

The author visited the families of two of the pupils in the school class discussed in 3.5.1, performing informal interviews. The intended content of the interviews is given in Appendix E.2. Due to language problems and other practical concerns, the author found it hard to follow the point-by-point schedule given in Appendix E.2, and therefore some of the questions were skipped. The first household (household no. 1) had three members; the pupil and his two parents. The second household (household no. 2) had two members; the pupil and one of her parents. A brief presentation of some key findings from the interviews will be given here.

Both households are connected to the public central heating network. The temperature in the winter is usually comfortable (typically 20-25°C, never too cold), although in household no. 1 it sometimes gets too hot and they have to open the windows. In both households, the temperature is at the same level throughout the day and on all days of the week, and there are no possibilities to adjust the amount of heat delivered from the central heating network. Household no. 1 owns an air conditioner but rarely use it, as it is old and inefficient (and therefore expensive). Instead, electrical fans are used on hot summer days to regulate the effective temperature. Apart from the special case of the old air conditioner, the members in household no. 1 do not usually think about the costs of electricity in their everyday life. Household no. 2 owns two air conditioners, which are used frequently during the summer to keep the temperature at a comfortable level. The regard electricity as cheap and therefore do not worry or think about the costs of electricity in their everyday life.

Household no. 1 does not own a car, and although the mother of the family expressed frustration about uncomfortable and long bus travels to and from work, the family does not plan to purchase a car. The main reason is that they think transport fuel is expensive. Household no. 2, who owns a car, also thinks that transport fuel is expensive. According to the parent, traffic congestion and high fuel prices both contribute to reducing their use of the car.

Both pupils said that although the air quality in Beijing is still bad at times, they have noticed considerable improvements in the last five years. With respect to the local air quality, they are optimistic about the future and think the positive trends will continue.

3.5.3 Migrant village visit

As was noted in Section 2.1, a large portion of the floating population in Beijing lives in enclaves of old farm houses. The author visited one such 'migrant village', with the aim of getting an overall impression of how people there live. One short interview was performed with one of the residents living in the village. The interviewee lived together with his wife and their child, and his occupation was to collect trash from the roads. The interviewee claimed that most of the residents in the village use coal for heating and cooking, but some use liquefied petroleum gas. His family used coal for heating and cooking. A pile of coal pieces was stacked up against the wall of the family's dwelling. According to the interviewee, his family used four coal pieces a day for cooking and boiling water. In the winter, they would use a couple of more pieces a day for heating. The price of each coal piece was approximately 0.6 yuan. The family had access to electricity, but rarely used it due to expensive prices. They did not own a refrigerator.

4 Results

The main results are presented in this chapter. Firstly, estimates of the direct and indirect household energy consumption (HEC) in Beijing in the reference year 2005 are presented in Section 4.1. Secondly, projections of energy use are presented in Section 4.2. Some of the results are presented by main consumption categories. The categories are defined in Tables C-2 and C-4. As in Chapter 3, the socioeconomic groups are denoted as: L: Low income; ML: Medium-low income; M: Medium income; MH Medium-high income; H: High income. T denotes 'Total', i.e. the average across all income groups.

4.1 Direct and indirect energy consumption in Beijing

Tables 4-1 and 4-2 show the estimates of direct and indirect HEC of urban and rural households, respectively. On average, the total HEC is 46.4GJ/capita for urban households and 35.1GJ/capita for rural households, when the use of biomass for energy purposes is excluded. If biomass use in rural households, amounting to 8.1GJ/capita, is included, the rural HEC is 43.2GJ/capita. Indirect HEC constitutes 76.1% of the total HEC in urban households and 46.0% of the total commercial energy consumption in rural households. In absolute terms, the per capita indirect HEC is more than twice as high in urban households as in rural households. In total, the energy consumption needed to support consumption in Beijing amounts to 685.1PJ.

Table 4-1: Annual direct and indirect HEC (GJ/capita) of five socioeconomic groups in urban Beijing

	T	L	ML	M	MH	H
Total	46.4	28.5	37.8	40.1	53.2	77.4
Total direct	11.1	7.8	9.0	9.1	11.3	19.4
Total indirect	35.3	20.8	28.8	31.0	42.0	58.0

Table 4-2: Annual direct and indirect HEC (GJ/capita) of five socioeconomic groups in rural Beijing

	T	L	ML	M	MH	H
Total (excl. biomass)	35.1	21.5	27.8	32.7	41.6	55.9
Total direct (excl. biomass)	19.0	12.0	16.1	18.2	22.9	27.4
Total indirect	16.1	9.4	11.7	14.6	18.7	28.4
Biomass	8.1	N/A	N/A	N/A	N/A	N/A

Figure 4-1 shows the composition of HEC for an average household in urban Beijing. The most important categories in terms of energy use are 'Food and beverages' (19.9% of total HEC), followed by 'Electricity, heat and household fuels' (16.0%). For transportation, the direct energy use associated with the burning of fuels in private vehicles (7.9%) is smaller than the sum of other transport related energy use (8.9%). 'Clothing and footwear' and 'Residence (excl. energy use in households)' represent 7.4% each, while 'Medicine and medical services' represent 7.3% and 'Culture and recreation' 7.0%. The four remaining consumption classes represent between 4.1% and 5.6% each.

The energy composition for rural households is shown in Figure 4-2. Note the slightly differently defined categories in Figures 4-1 and 4-2. The rural HEC dominated by the use of electricity and fuels in the households, with use of commercial direct energy in households and use of biomass representing 39.8% and 18.8%, respectively. 'Residence (excl. energy use in households)' and 'Food and beverages' are two other important categories in Figure 4-2, each representing 9.6%. Fuel for transport is of minor importance (4.0%).

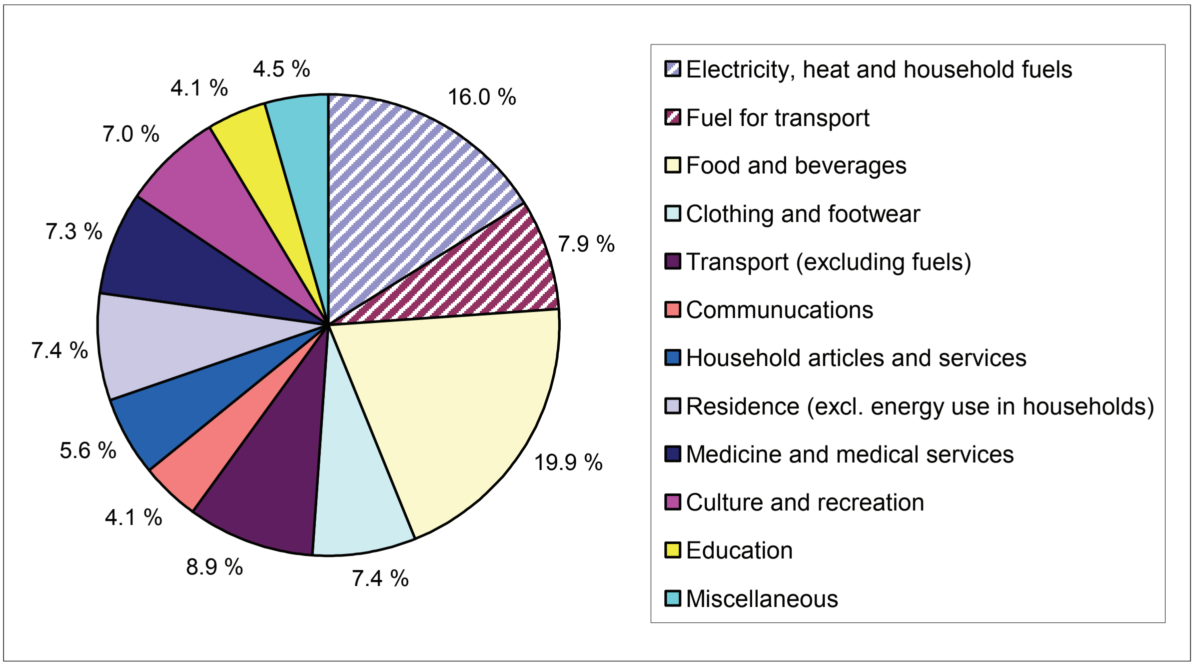

Figure 4-1: Share of HEC (%) by main consumption categories for average urban Beijing household. Striped consumption classes represent direct HEC, non-striped classes represent indirect HEC.

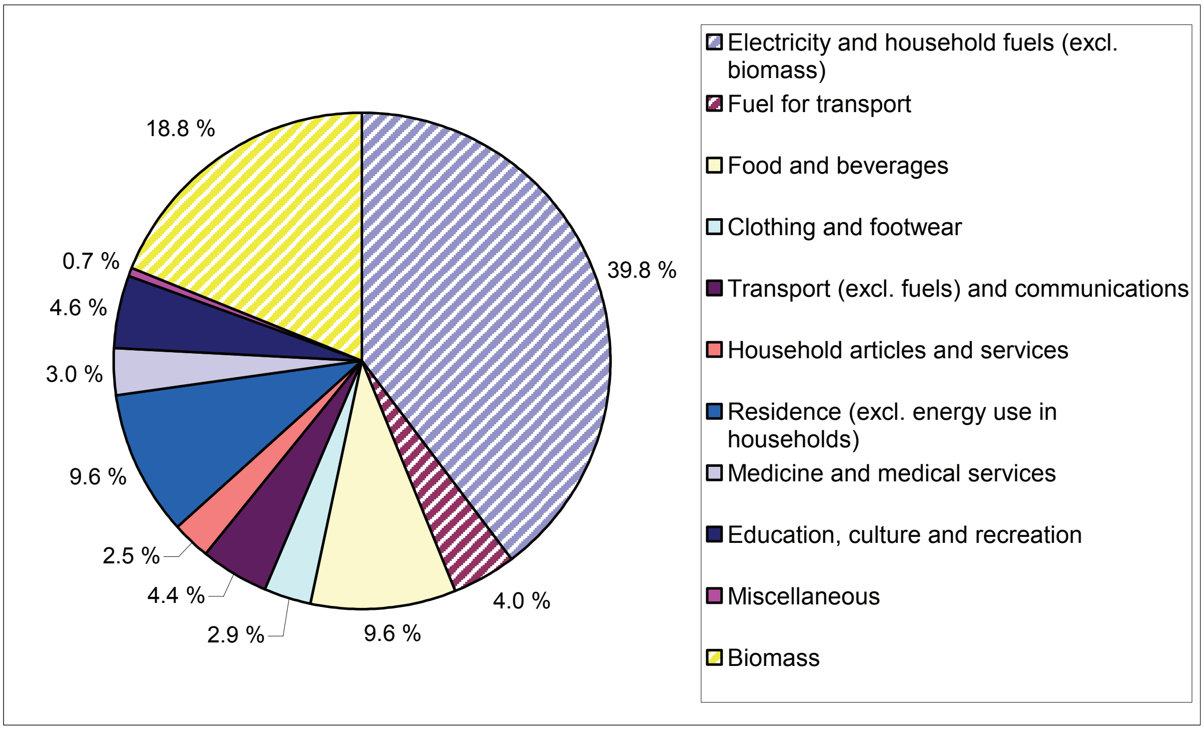

Figure 4-2: Share of HEC (%) by main consumption categories for average rural Beijing household. Striped consumption classes represent direct HEC, non-striped classes represent indirect HEC.

Figures 4-3 and 4-4 show the HEC, decomposed into main consumption classes, versus annual total expenditure level. Similarly as for previous figures in the present report, linear interpolation was used to establish intermediate values (i.e. variations within income groups) in Figures 4-3 and 4-4.

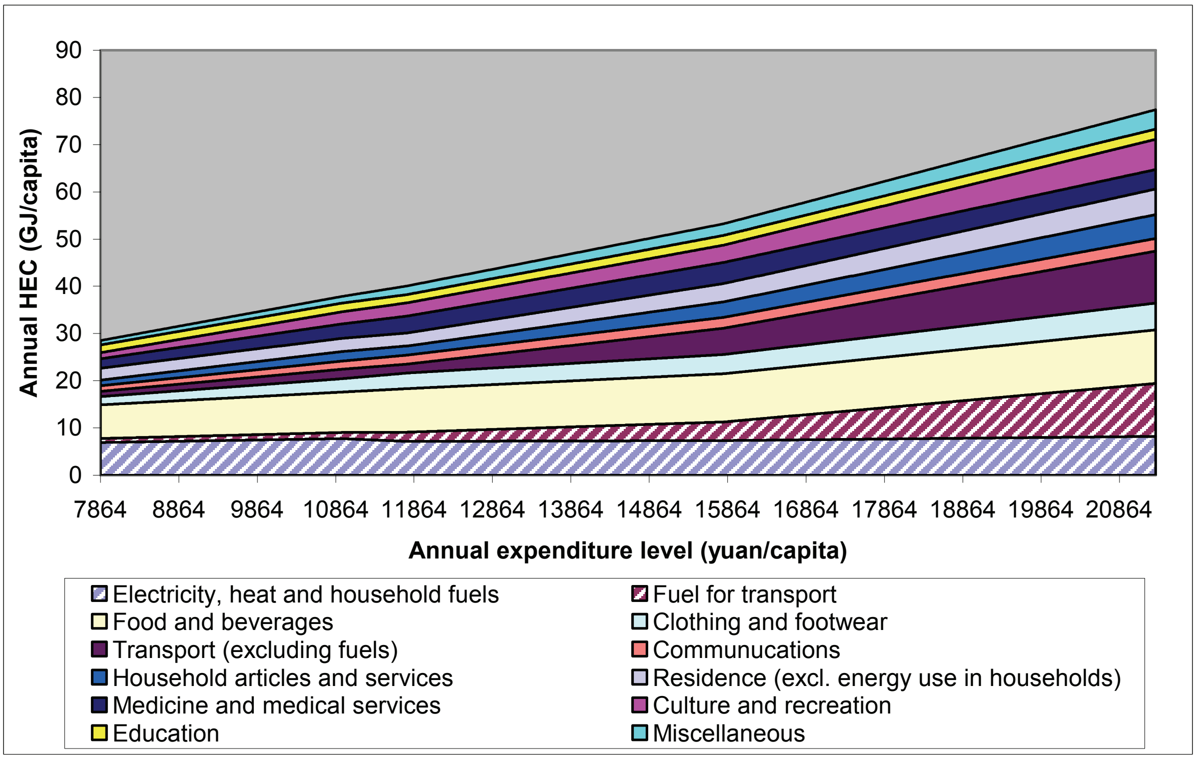

Figure 4-3: Annual HEC (GJ/capita) by annual expenditure level (yuan/capita) in urban Beijing. Striped consumption classes represent direct HEC, non-striped classes represent indirect HEC.

For urban households (Figure 4-3), perhaps the most striking trend is the strong positive correlation between transport related energy use (i.e. the consumption classes 'Fuel for transport' and 'Transport (excluding fuels)') and total expenditure level. The correlation is strongest for the highest income households, i.e. in upper end of the horizontal scale of Figure 4-3, with the use of fuel for transport increasing from 3.9GJ/capita for the medium-high income households to 11.2GJ/capita for the high income households. As opposed to the sharp rise in transport related energy use with income, energy use related to 'Food and beverages', 'Electricity, heat and household fuels' and 'Education' are quite stable. In spite of high-income households having on average 2.7 times higher income than the low-income households, the direct use of energy in households is only 1.2 times higher. Similarly, the energy use related to 'Education' and 'Food and beverages' is 1.3 and 1.6 times higher, respectively. For the consumption classes 'Communications', 'Residence' and 'Medicine and medical services' there is a modest increase in energy use with rising income. For 'Clothing and footwear', 'Household articles and services', Culture and recreation' and 'Miscellaneous', there is a strong positive correlation between energy use and income, although far from as strong as for transport.

The aggregation of electricity, heat and household fuels into one single category masks some changes in the composition of energy use with income. As is shown in Table 4-3, electricity, natural gas and heat consumption increase with rising income, while for coal and LPG consumption this is not the case. Although the consumption of coal fluctuates, there seem to be a negative correlation between coal consumption and income, with the three largest values for coal consumption belonging to the three socioeconomic groups with the lowest incomes. For LPG, there is a clear negative correlation between consumption and income.

Table 4-3: Annual direct energy use in urban households (GJ/capita) by type for five socioeconomic groups

	T	L	ML	M	MH	H
Electricity	2.0	1.6	1.8	2.0	2.2	2.5
Coal	1.0	1.3	1.6	0.9	0.6	0.8
Liquefied Petroleum Gas (LPG)	1.1	1.3	1.1	1.1	1.1	1.0
Natural gas	1.7	1.4	1.6	1.6	1.8	2.3
Heat	1.6	1.4	1.5	1.6	1.6	1.7

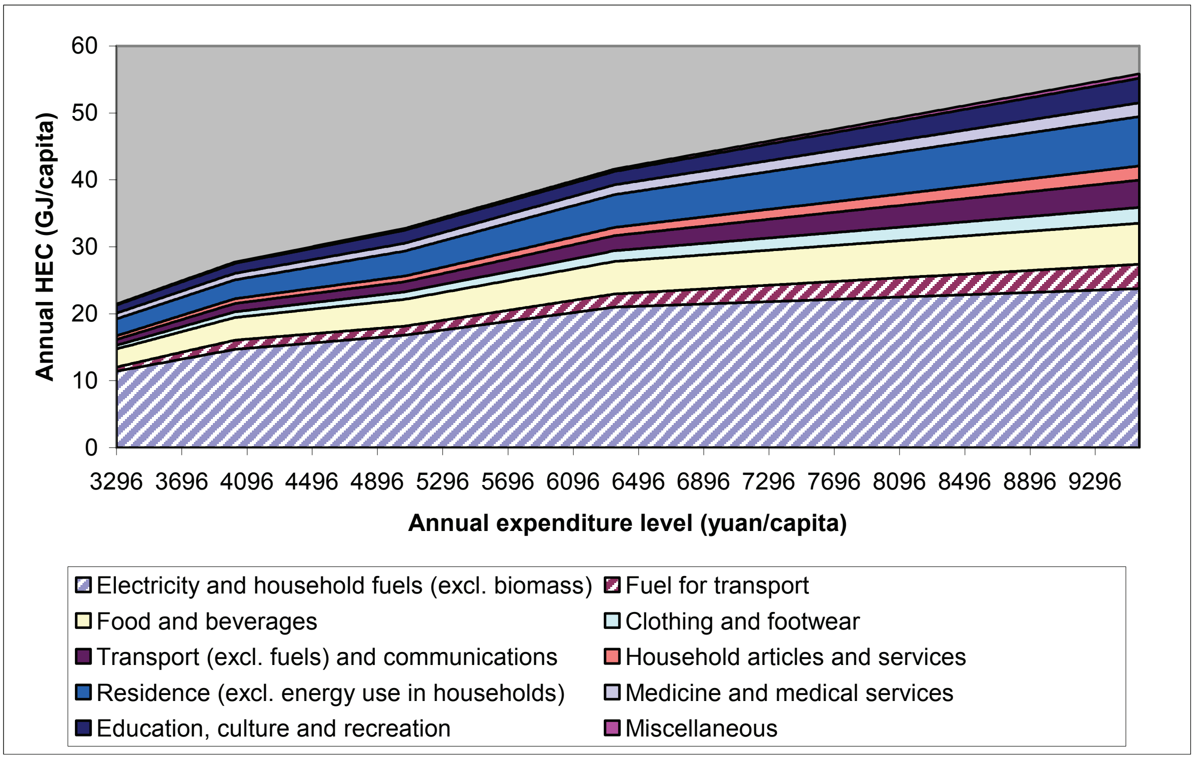

Figure 4-4: Annual HEC (GJ/capita) by annual expenditure level (yuan/capita) in rural Beijing. Striped consumption classes represent direct HEC, non-striped classes represent indirect HEC.

There is a strong positive correlation between transport related energy use and income for rural households, although the trend is less distinct than for urban households. Next to transport, ‘Clothing and footwear’ and ‘Miscellaneous’ show the largest percentage increase, but the absolute values are relatively low. There is a more distinct increase in the direct use of energy in households (excluding biomass) for rural households than for urban households, with the high income rural households using more than twice the amount compared to the low income households. Energy use associated with ‘Food and beverages’ increase with a factor of 2.3 from the lower end of the income scale to the upper end.

Figure 4-5 shows the energy intensity of consumption, i.e. HEC normalised with total expenditure level, versus total expenditure level. The much larger values for rural households than for urban households are primarily due to the large numbers for coal consumption in rural households. For rural households, there is a clear trend that the energy intensity declines with rising income, although some fluctuations are evident. The significant drop in energy intensity between the rural medium-high income households and the rural high income households is entirely caused by changes in the composition of direct energy use. For urban households, the highest values for the energy intensity are found at the lower and upper end of the income scale. Increases in indirect and direct transport related energy use is the dominant factor causing the energy intensity to increase in the upper end of the income scale.

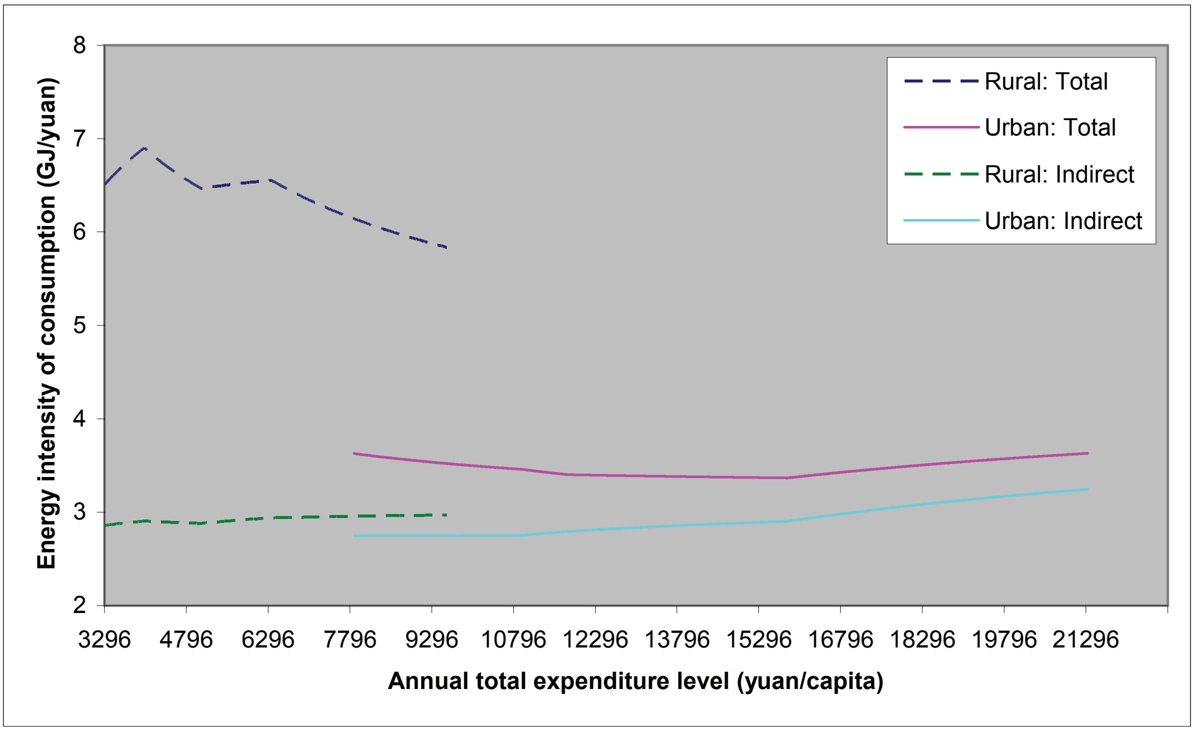

Figure 4-5: Energy intensity of consumption (GJ/yuan) (excluding biomass) by annual total expenditure level (yuan/capita) for urban and rural Beijing households

4.2 Energy projections

In the present section, the results of the three analyses introduced in Section 3.4 are presented. The analyses are dealt with in the same order as in Section 3.4. The results of the analyses of how distribution of wealth affects HEC is presented first (Section 4.2.1), followed by a presentation of estimated energy impacts associated with moving the entire urban population up in income corresponding to the high-income group of today (Section 4.2.2). Finally, projections of energy use towards 2015 are presented in Section 4.2.3.

4.2.1 Redistributions of wealth

The main results, divided into total HEC, direct HEC and indirect HEC, are shown in Table 4-4. Total HEC is rather constant for the three cases. With the more even distribution, total HEC is 99.0% of that of the actual (reference) distribution, whereas for the more uneven distribution the number is 100.9%. The deviations from the reference distribution are almost entirely caused by differences in the direct HEC.

Table 4-4: Annual HEC (GJ/cap) for three distributions of wealth

	Even distribution of wealth	Reference	Uneven distribution of wealth
Total	48.0	48.5	48.9
Direct	10.7	11.1	11.5
Indirect	37.3	37.4	37.5

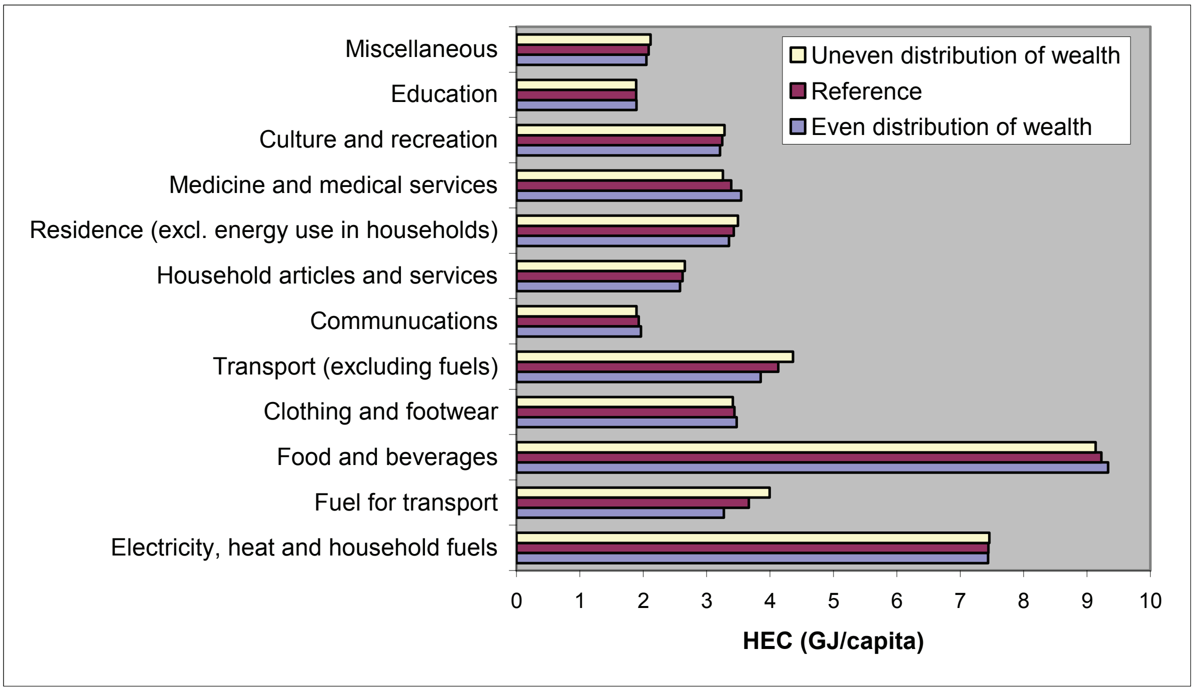

Figure 4-6: Annual HEC (GJ/capita) by main consumption categories for three distributions of wealth

In Figure 4-6, HEC is decomposed into main consumption categories. When measured in absolute terms, the by far largest deviations from the reference case are found for the two transport categories ('Fuel for transport' and 'Transport (excluding fuels)'). These two categories also deviate the most in percentage terms, followed by 'Medicine and medical services'.

Table 4-5: Annual direct energy use in households (GJ/capita) by type for three distributions of wealth

	Even distribution of wealth	Reference	Uneven distribution of wealth
Electricity	1.99	1.98	1.96
Coal	1.02	1.03	1.06
Liquefied Petroleum Gas (LPG)	1.12	1.13	1.14
Natural gas	1.71	1.71	1.72
Heat	1.56	1.55	1.54

As shown in Table 4-5, deviations from the reference distribution in the use of electricity, heat and households fuels are relatively small.

4.2.2 High-income households as trendsetters

Moving the entire urban population up in income corresponding to the high-income group of today implies that the direct HEC increases from 11.1GJ/capita to 19.4GJ/capita and the indirect HEC increases from 35.3GJ/capita to 58.0GJ/capita. This means that in total, HEC increases from 46.5GJ/capita to 77.4GJ/capita (evident from Table 4-1). In percentage terms, this is equivalent to increases of 74.8%, 63.8% and 66.5%, for direct, indirect and total HEC, respectively. In terms of total HEC in urban Beijing (measured in PJ), the difference between the two cases is 397.5PJ.

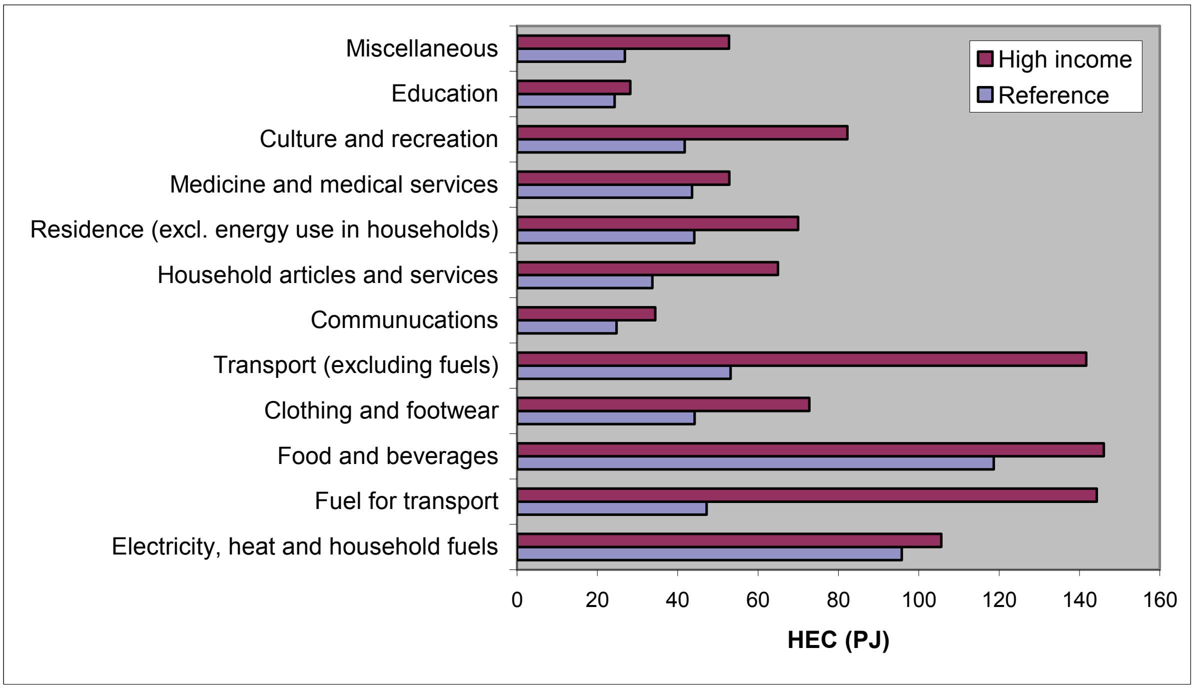

Figure 4-7: Annual HEC (PJ) by main consumption categories for reference case and high-income case

Figure 4-7 compares HEC in urban Beijing (measured in PJ) by main consumption categories for the actual situation in 2005 and the situation where all residents belong to the high-income group. By far, the largest contributors to the higher HEC in the latter situation are the two transport related consumption categories. Comparing the two cases, energy use related to fuel for transport increases more than twofold, while the energy use related to 'Transport (excluding fuels)' increases with a factor of 1.7. Substantial increases in energy are also found for the categories 'Clothing and footwear', 'Household articles and services', 'Residence (excl. energy use in households)', 'Culture and recreation' and 'Miscellaneous'. The remaining categories are less important as contributors to increased HEC.

Table 4-6: Annual direct energy use in households (PJ) for reference case and high-income case

	Reference	High-income
Electricity	25.43	31.57
Coal	13.31	10.44
Liquefied Petroleum Gas (LPG)	14.52	12.58
Natural gas	22.03	28.93
Heat	19.91	21.54

As in Section 4.1, the aggregation of electricity, heat and household fuels into one category masks some changes in the composition of direct energy use. A more detailed presentation of direct energy use in households is given in Table 4-6. As one would expect from Table 4-3, the consumption of electricity, natural gas and heat is larger in the situation where all residents belong to the high-income group, whereas the use of coal and LPG is smaller.

4.2.3 Projections of energy use: 2005-2015

The projections of HEC towards 2015, aggregated into total, indirect and direct HEC, are shown in Tables 4-7 (in units GJ/capita) and 4-8 (in units PJ). For both scenarios, there is a substantial increase in HEC from 2005 to 2015. On a per capita basis, the total HEC increase with a factor of about 2.3 from 2005 to 2015, regardless of scenario. Similarly, direct and indirect HEC increases with factors of approximately 2.2 and 2.4, respectively. Due to the growing population, the increases in HEC are even higher when measured in PJ. The results are about the same for the two scenarios. The numbers for total HEC are slightly higher for the scenario with a more uneven distribution of wealth.

Table 4-7: Annual HEC (GJ/capita) in 2005 and 2015 for two equity scenarios

	2005	2015: Even distribution	2015: Uneven distribution
Total	46.4	107.97	108.54
Total direct	11.1	24.28	25.02
Total indirect	35.3	83.69	83.52

Table 4-8: Annual HEC (PJ) in 2005 and 2015 for two equity scenarios

	2005	2015: Even distribution	2015: Uneven distribution
Total	596.68	1660.41	1669.11
Total direct	142.91	373.34	384.78
Total indirect	453.77	1287.07	1284.33

Figure 4-8 shows HEC in 2005 and 2015 by main consumption classes. Again, the transport related categories stand out, increasing much more than any other categories. From 2005 to 2015, energy use for transport fuel increase with factors of 4.3 and 4.5, for the two scenarios respectively. If population growth is also taken into account, the energy use for transport fuel increases with 195.9PJ in Scenario 1 (even distribution) and 205.7PJ in Scenario 2 (uneven distribution). Consumption classes with slightly higher values for Scenario 1 are largely levelled out by consumption classes with slightly higher values for Scenario 2, resulting in approximately equal values for the total indirect HEC. In Figure 4-8, there is a modest growth in the total use of direct energy in households from 2005 to 2015. The difference in direct energy use in households between the two scenarios is negligible. From Figure 4-9 it is evident that the increase in total use of energy in households is caused by increased use of electricity, heat natural gas. Coal and LPG consumption, on the other hand, is reduced, in spite of increasing population numbers.

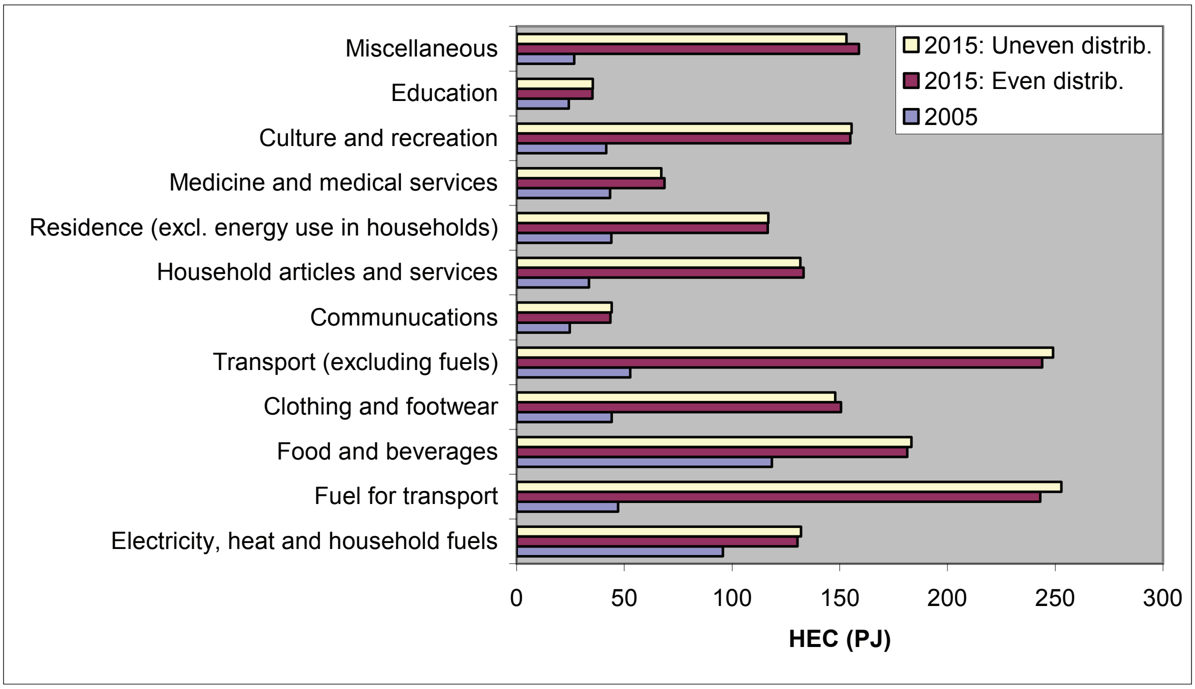

Figure 4-8: Annual HEC (PJ) urban Beijing in 2005 and 2015 by main consumption categories

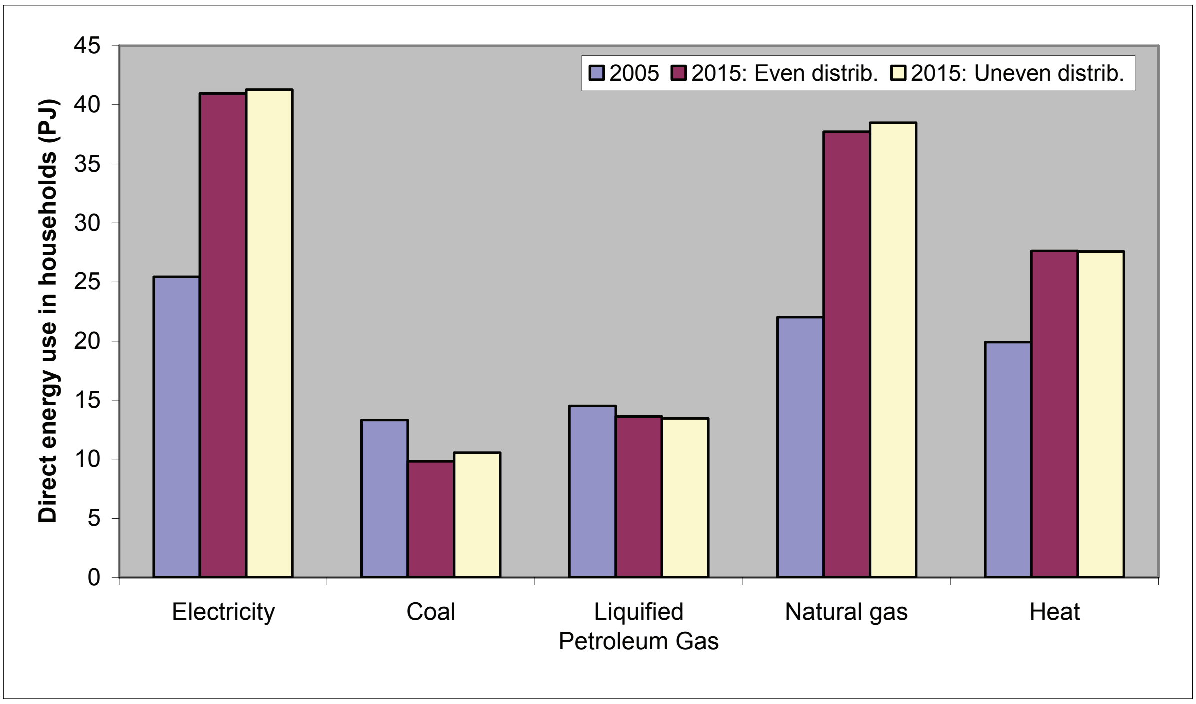

Figure 4-9: Annual direct energy use (PJ) in urban Beijing households in 2005 and 2015

5 Discussion

Some discussions regarding background information, assumptions and methodologies have been given in previous chapters of this report, as deemed appropriate. The present chapter gives a final discussion, focusing on the results presented in the previous chapter and on possible implications of the results for policy making. The final discussion is divided into three main parts. Section 5.1 concerns itself with findings on household energy consumption (HEC) today, while in Section 5.2 the focus is on HEC in the future. Some of the results on HEC in Beijing are compared with similar results produced by other studies of other countries. It should be noted that results from different studies may not be fully comparable, as there are likely to be differences in methodologies and underlying assumptions. Also, the studies are from different years. Finally, Section 5.3 discusses uncertainties and limitations in the present study.

5.1 Household energy consumption today

HEC was estimated to 46.4GJ/capita for urban households and 35.1GJ/capita for rural households. The HEC of the average Beijing households is then 44.5GJ/capita. In the literature, estimates of per capita HEC varies greatly between different countries, both in terms of absolute values and in the share of the various activities (Hertwich 2005). Estimates of total HEC ranges from 12.6GJ/capita in India in 1993-1994 (Pachauri and Spreng 2002) to 346.9 GJ/capita in the USA in 1997 (Bin and Dowlatabadi 2005). For countries in the European Union in 1994, HEC has been found to range from 59.6GJ/capita in Poland to 151.9GJ/capita in Sweden (Reinders et al. 2003)[7]. Hence, HEC in Beijing is lower than in many OECD countries, in spite of the relatively low energy efficiency characterising much of China's industry, transport and building sectors.

For urban and rural households, respectively, the estimates of indirect HEC in Beijing in 2005 are about 1.7 and 3.2 times greater than the estimates of Peters et al. (2006a) of indirect HEC in China in 2002. Correspondingly, expenditure levels are 2.1 and 5.1 times greater, when inflation has been adjusted for. There are several factors that can cause discrepancy between Beijing and average China values, one of them being different consumption patterns. Differing practices of attributing expenditures to industry sectors in the two studies is another possible explanation for the discrepancy between the results of the two studies.

It was found that total HEC in the whole of Beijing amounted to 685.1PJ. By comparison, the (direct) energy consumption within Beijing's geographical boundaries amounted to 1618.4PJ in 2005 (BMBS 2006). Thus, the consumption based energy use (HEC) in Beijing amounted to 42.3% of the actual energy use occurring in all sectors in Beijing. This comparison can be said to be artificial, not only because national and not Beijing specific input-output tables were used in the calculation of indirect HEC, but also because the economy of Beijing obviously is closely interlinked with the rest of China. Nevertheless, the conclusion can be drawn, both from the results of this study and from numerous other studies, that a significant portion of the energy use in the society can be linked with consumer activities. This is because all products and services produced in an economy are ultimately meant for consumption, largely by households. Even if products are not produced directly for consumption, they are

[7] Excluding the special case of Luxembourg, with HEC value (192.4 GJ/capita) towering above all other values

typically produced to make consumption of other products possible. In this perspective, the share of 42.3% may even seem small. In the US, the total HEC has been found to account for 85% of all energy use (Bin and Dowlatabadi 2005). At in least in part, the lower value for Beijing may be explained by a net export, either to other regions of China or to foreign countries, of energy embedded in goods. As noted previously, the energy embodied in China's domestic production of goods for exports constituted 28% of the country's total energy consumption in 2004. By comparison, the energy embodied in Chinese imports constituted 12% of the Chinese energy demand (IEA 2007).

The finding that a significant portion of the energy use in the society can be attributed to households is highly relevant for policy makers. Possible gains from behavioural and lifestyle changes are not limited to what can be achieved through more efficient and frugal use of electricity, heat and fuels. Consumers' indirect influences on energy use are substantial, in urban Beijing more than three times greater than the direct influences, and herein lay a great potential to improve the energy efficiency of the society. Measures to reduce indirect HEC can be taken not only on the production side; by making production processes more efficient, but also on the demand side; by stimulating to increased consumption of goods of low energy intensity at the expense of goods with high energy intensity. Measures that can be taken on the demand side include: informing consumers through such means as environmental labelling; using economic instruments to influence behaviour or consumption patterns; promoting environmental consciousness through education, information campaigns, etc. Authorities should put emphasis on exploiting the untapped potential that lies in promoting more sustainable consumption patterns. To better be able to select areas of concentration and identify which lifestyles that are more sustainable, efforts should be made to increase our knowledge and understanding of how household activities are related to energy use in the society. The tools input-output analysis and life cycle assessment, and the combination of the two, can aid policy makers in developing sustainable consumption policies (Hertwich 2005).

Both for the urban and rural households there is a strong positive correlation between total HEC and income. This is a result that has previously been produced in numerous other studies for other countries. Vringer and Blok (1995) found, in their study of Dutch households in 1990, that a doubling in expenditure level leads to an 83 % increase in total HEC, while a doubling in income level leads to a 63 % increase. In his review of different studies, Hertwich (2005) found that the increase in HEC with a doubling of income varies between 67% for India in 1993-94 and 90% for Denmark in 1995. According to the results presented in Section 4.1, a doubling in expenditure levels causes the urban and rural HEC, respectively, to increase with 100.1% and 84.2%. The ratio between net income and expenditure level increases with rising income. For urban households, the ratio is 1.1 for the low-income households and 1.6 for the high-income households. The upward trend is even more evident for rural households, where the ratio increases from 0.9 to 1.7 when moving from the lower to the upper end of the income scale. Reflecting the widening gap between income and expenditure level, a doubling of net income leads to significantly lower percentage increases in HEC than a doubling in expenditures. A doubling of net income leads to increases in HEC of 60.3% for urban households and 37.2% for rural households. These numbers are lower than in all studies evaluated by Hertwich (2005). Two possible explanations for this are that the ratio between income and expenditure level is particularly high for Beijing households, or that income is defined differently (e.g. with regards to inclusion or exclusion of taxes) in the different studies. This has not been investigated further.

The share of direct HEC to total HEC is 24.0% in urban households, 54.0% in rural households and 27.8% in the whole of Beijing. By comparison, the share was 47% in India in 1993-1994 (Pachauri and Spreng 2002), 40% in South-Korea in 2000 (Park and Heo 2007) and 39% for Brazil in 1995-1996 (Cohen et al. 2005). In the 11 EU states evaluated by Reinders et al. (2003), the share of direct HEC to total HEC varies from 34% (Poland) to 64% (Finland and Sweden). Some studies of HEC in developed countries have shown that while the indirect energy use increase steadily with rising income, direct energy use tends to flatten out (Hertwich 2005). The results presented in Section 4.1, indicating a strong positive correlation between consumption of fuel for transport and income, suggest that at this point in time this conclusion is not valid for Beijing. The total direct use of energy in households, however, does seem to be approaching saturation, particularly in urban areas. Interestingly, the rather constant values for energy use in households across income groups masks differences in types of energy.

In urban households, ‘Food and beverages’ is the single consumption category with the largest energy impact. In rural households, it is surpassed only by the categories representing direct energy use in households. While it is true that in the future, energy consumption related to food is likely to become less important relative to other consumption categories, it can also be argued that the substantial amount of energy use associated with food consumption today calls for the attention of policy makers. Possible measures to reduce the energy intensity of food consumption includes encouraging consumption of less energy intensive food products, and to stimulate to reduced use of fertilizers.

For rural households, there is a huge consumption of coal, constituting 40.2% of the total HEC. Whether this result is realistic has been discussed in previous sections of this report, and will not be discussed further here. If the number for rural coal consumption is accurate, improving the energy efficiency of cooking and heating in rural areas should be a major priority area for the local government. The thermal efficiency of home coal stoves in rural families in China is generally significantly lower compared with utilisation of commercial energy in urban areas (Xiaohua and Zhenmin 2003). There may lay a significant energy conservation and pollution reduction potential in enhancing the thermal efficiency of coal stoves, as well as in promoting a shift from the use of coal towards LPG and electricity. A realisation of this development may also yield significant co-benefits related to indoor environment and health, as household solid-fuel use in China often is associated with health-damaging pollution (Edwards et al. 2004).

5.2 Household energy consumption in the future

With constant technology (i.e. neglecting changes in efficiency over time), moving the entire urban population of Beijing up in income corresponding to the high-income group would result in a 66.5% increase in total HEC. The energy scenarios towards 2015, also assuming constant technology, suggest that total urban HEC in 2015 will be 2.8 times greater than in 2005. The dramatic increase in total HEC are caused by two factors; population growth and growth in absolute income. Changing consumption patterns also affects the future HEC, but as will be discussed later in this section, this was found to be of minor importance. In spite of a considerable net influx of residents (more than 2.5 million) to urban Beijing during the projection period, the effect of population growth on total HEC was found to be significantly lower than the effect of income growth. Assuming constant population, total urban HEC in 2015 will be 2.3 times greater than in 2005.

While there is no doubt that increases in expenditure levels and population will contribute to growth in HEC, the magnitude of the actual growth in future HEC is obviously influenced also by other factors, perhaps most notably by efficiency improvements. Future HEC will largely be determined by to what extent improvements in efficiency can offset the effects of higher consumption levels, in what Peters et al. (2007) aptly describes as a “race between increasing consumption and efficiency gains”. As has been noted before in this report, the Chinese government aims to reduce the energy intensity of the country by 20% between 2006 and 2010, equivalent to an annual reduction of 4.66%. Also, they have set a target of quadrupling the per capita GDP from 2000 to 2020, while only doubling primary energy consumption. Assuming that the annual reduction of 4.66% in the period 2006-2010 is achieved, and that the energy intensity continues to decline at an annual rate of 4.00% towards 2015, the intensity will be 35.8% lower in 2015 than in 2005. If this improvement in energy intensity is representative also for the HEC of Beijing, the energy consumption will be 1.8 times greater than in 2005 (as opposed to 2.8 times greater with constant technology). On a per capita basis, the HEC will be 1.5 times greater (2.3 with constant technology). Hence, even with overall energy efficiency improvements corresponding to the national government’s ambitious targets, there will be a substantial growth in HEC in urban Beijing, according to the results.

The energy intensity of urban households was found to be lowest for the medium-income households, with higher values at the lower and upper end of the income scale. This suggests that there will be a gain in terms reduced HEC if wealth is more evenly distributed across urban income groups. However, the variations in energy intensity with income (or expenditure level) are relatively small, and according to the results, there is little to gain in terms of reduced overall HEC by distributing economic growth more evenly. Also, the conclusion can be drawn the consumption patterns will be of minor importance, compared to income and population growth, in contributing to increased overall HEC.

Energy consumption related to transport and direct energy consumption in households is discussed in Sections 5.2.1 and 5.2.2, respectively. In Section 5.2.3, some closing remarks are given regarding lifestyle and HEC in a more broad perspective.

5.2.1 Transport

In auto industry policies launched by the central government in 1994 and 2004, production and consumption of private cars were seen as an important economic pillar. A number of policies in Beijing have clearly bore the stamp of an official desire to develop a car-based transport system (Liu et al. 2007). Growth in private car ownership have increased people’s mobility and thus contributed to life quality improvements. Without doubt, mobility plays an essential role in human lives by improving accessibility to amenities valued by individuals. Lack of mobility may hinder individual’s access to amenities important for human well-being, such as consumer goods, education, employment, health care and leisure activities (WBCSD 2001). However, as negative aspects of car transport have become more and more evident, it has also become a major reason for concern for the local authorities. Since 1995, a number of measures have been taken to reduce vehicular emissions and decrease the demand for motorised transportation in Beijing. The measures include land use and traffic planning, emission control of in-use vehicles, new-car emissions standards, fuel quality improvements and fiscal incentives (Hao et al. 2006). The results of the present study indicate that future income growth will be accompanied by dramatic increases in transport related energy use. Both when attributing the consumption of the high-income group to the entire population and when making energy projections towards 2015, the two consumption categories ‘Fuel for transport’ and ‘Transport (excluding fuels)’ stand out with increases in absolute energy use towering well above the increases of all other single consumption categories. If all urban residents were to adopt the lifestyle of the high-income group, the demand for fuel for transport would increase more than threefold. The conclusion can be drawn that in an energy and emissions perspective, transport is a highly important area to focus on for policy makers. The conclusion is further strengthened by the fact that vehicular emissions now constitute the main source of air pollution in Beijing, of which cars are the largest contributor (Hao et al. 2006; Liu et al. 2007). It is of the utmost importance that policies reflect that the growth potential in private car transport in Beijing is huge, and that failure to control vehicular emissions and traffic volume may have severe consequences. Possible downsides of a car based transport system are not limited to air pollution and energy supply concerns, but also include congestion, noise pollution and traffic accidents.

Globally, technological advances and utilising the most efficient and lowest-emitting cars available offers excellent opportunities to reduce energy use and harmful emissions from car transport, compared with a business as usual scenario (Kahn Ribeiro et al. 2007). Stimulating policies promoting fuel substitution in buses and taxis, more stringent new-car emissions standards and fiscal incentives to stimulate sales of more efficient vehicles than vehicles fitting the highest efficiency class, total vehicular emissions in Beijing have not increased between 1998 and 2003, despite of a growth in vehicle population of 60% in the same period (Hao et al. 2006). To mitigate the environmental problems associated with future growth in car transport, it is vital with continued strong efforts from the central and local governments to promote technological innovation and stimulate employment of less environmental intensive cars. Authorities should also consider measures to ensure that future technologies are applied to reducing the pollution intensity rather than to increasing the engine power or vehicle mass.

Efficiency improvements and advances in technology are unlikely to be sufficient if increasing environmental impacts from private transport in Beijing are to be avoided (Liu et al. 2007). Private cars consume far more energy than other surface passenger modes (Kahn Ribeiro et al. 2007), and thus there is a considerable potential to reduce environmental impacts by canalising future growth in mobility towards non-motorised transport means or public transport, rather than private cars. In policy making, the authorities should refrain from encouraging private car use, and rather consider measures such as fuel taxes and congestion charges. Remembering that higher mobility levels can improve individual’s quality of life, it is essential that public transport services are expanded and improved, so that Beijing’s residents still can enjoy the benefits of high mobility levels. As opposed to a transport system heavily based on private car traffic, benefiting the well-off at the expense of the needs of the poor, a transport system where emphasis is put on offering affordable public transport services will be more beneficial for the poor (Ahmed et al. 2008).

Interestingly, but not surprisingly, transport related energy use is the type of energy use that is most strongly affected by changes in the distribution of wealth. In the energy projections towards 2015, the consumption of fuel for transport is 4.0% higher in the scenario with more uneven economic growth than in the scenario with more even growth. Hence, reversing the trend of widening income inequality in urban Beijing can give a contribution in reducing private car travel that, albeit relatively small, is not necessarily insignificant. Also worth noticing is that the floating population, of which the average income is significantly lower than that of the low-income group in the urban Beijing SCE, is not included in the scenario analysis. Canalising income growth to the floating population and lifting the floating population up in income-level corresponding to the low-income group may very well lead to increased demand for public transport services, but will presumably give only a negligible increase in private vehicle use.

5.2.2 Direct energy consumption in households

Great quantities of buildings are currently being constructed in China and Beijing. At the end of 2005, 7.8 million m^2 of residential floor space were under construction in Beijing (BMBS 2006). According to Taylor et al. (2001), it is highly likely that half of the total urban building stock in China in 2015 will have been constructed after 2000. Construction activities are significant contributors to air pollution and resource depletion, much more so than in European and North-American countries, e.g. due to the higher construction rates and lower efficiency in the production of materials (Yang and Kohler 2008). If large environmental impacts from building construction activities were a price that China had to pay to provide its residents with a well-designed, efficient and long-lasting building stock, it would be unfortunate. Much more unfortunate, though, is the case where the large environmental impacts are consequences of construction of buildings with poor lasting-ability and energy inefficient designs. Unfortunately, it seems that the latter case is closer to the truth than the former. Although serious efforts have been undertaken by the central government to improve the energy efficiency of buildings, including initiating pilot projects for trying out new technologies and issuing energy standards for buildings, many new buildings are still constructed on old, inefficient design principles[8] (Taylor et al. 2001; Yang and Kohler 2008). The average urban residential consumption of heating it roughly two to three times as much as that required by new standards in European countries with similar climatic conditions (Yang and Kohler 2008). According to a survey conducted by the Chinese Ministry of Construction, only 23% of the newly constructed buildings from 2001 to 2004 were in compliance with energy-saving codes (Yang and Kohler 2008).

On the basis of the results of the energy projections presented in Section 4.2, one may draw the conclusion that since the near future overall increase in direct energy use in households is relatively small, direct energy use in households is less important to focus on than other types of energy use with higher increases. However, this may be a premature conclusion, as the results fail to reflect that some decisions made today affect energy use over longer time periods than others[9]. For example, while the design principles used in constructing cars today will largely lock the efficiency level of car use for maybe 10-15 years (the lifetime of a car), the design principles used in constructing buildings today will largely lock the efficiency level for several decades, perhaps more than 50 years. To avoid long-term lock-ins of inefficient capital, constructing more energy efficient buildings should be given high priority by central and local governments, and serious efforts should be made to secure enforcement of the energy standards for buildings. Due to the long life time of buildings, it is also important to consider opportunities for reducing energy use by renovation. As is pointed out by Yang and

[8] (Taylor et al. 2001) reports that the Beijing may be the leading province in China in terms of constructing energy efficient buildings, though.
[9] Of course this conclusion may be premature also for other reasons, but here the author would like to focus on the time aspect.

Kohler (2008), it may also be wise to modulate the scope of construction activities in the short term to allow technical progress and dispersion of information and know-how.

It should be noted that the estimates of central heating energy by income group is highly uncertain. In lack of better alternatives, the energy for central heating was distributed among income groups on the basis of differences in household size. In the future, if floor space per capita continues to increase, household size continues to decrease and income growth is accompanied by increasing demand for indoor comfort, it seems likely that there will be a significant increase in the demand for heating. It is possible that the latent demand for space heating is significantly underestimated in the present report. As is evident from Figure 2-19, percentage growth in floor space per capita has been much higher than the percentage decrease in household size in the past 15 years in Beijing.

Experiences from many countries show that performance standards and labels for electrical appliances are an effective way to control electricity consumption. The Intergovernmental Panel on Climate Change regards performance standards and labels as one of the most cost-effective instruments across the economy to reduce greenhouse gas emissions, with typically large negative costs (Levine et al. 2007). Figure 2-13 indicates that electricity use of refrigerators constitute a substantial portion (37%) of the total residential electricity consumption in urban Beijing. The numbers in Figure 2-13 are slightly outdated, and due to the increasing number of appliances hold by households, refrigerators presumably constitute a smaller share today than what is indicated by Figure 2-13. Still, the electricity consumption of refrigerators requires serious attention. A national energy efficiency standard for refrigerators has been issued by the central government and is expected to give large energy savings. However, if large annual energy savings are to be sustained in the long run, it is vital that the standards are regularly updated (Lu 2007).

Both in urban and rural households, ownership of clothes-washers, refrigerators and colour-televisions vary relatively little with income, indicating that ownership rates have already reached saturation or are approaching saturation. Air conditioner ownership on the other hand, increases significantly with rising income, particularly in rural households. Thus, under the assumption that households becoming more affluent will adopt the lifestyles of the already affluent households, future income growth will be accompanied by a significant increase in the number of air conditioners hold by households. It seems plausible to conclude that air-conditioners will be the most important single electrical appliance contributing to growth in residential electricity consumption in the near future. If the entire urban and rural populations are moved up in income corresponding to the urban and rural high-income groups, respectively, there would be an increase in the total air conditioner stock of more than 2.5 million units. With a unit energy consumption of 1.4GJ/year in urban households and 1.35GJ/year in rural households (Zhou et al. 2007), the resulting increase in energy use would be 3.5PJ, i.e. 10.8% of the total residential electricity consumption in 2005. This implies that regulating the efficiency of air conditioners may yield significant energy savings. The Chinese government published a revised standard on energy-efficiency for air conditioners in 2004, with the first tier going into effect in 2005 and the second taking effect at the start of 2009. In addition, air conditioners are labelled according to their energy performance. With the introduction of the second tier in 2009, the minimum energy requirements will be among the most stringent in the world (Lin and Rosenquist 2008). According to the analysis of Lin and Rosenquist (2008), the energy standards for air conditioners will yield cumulative national energy savings of 330 billion kWh (approximately 1200 PJ) by 2020, with cumulative CO_2 reductions almost adding up to the entire European commitment under the Kyoto regime.

5.2.3 Closing remarks

As was noted already in Chapter 1, it is becoming increasingly evident that without concurrent efforts on the demand side of the economy, environmental gains achieved through efforts on the production side of the economy will fall short of addressing the major environmental problems humanity is facing (UNEP 2002). Rebound effects, i.e. behavioural or systems responses to energy efficiency measures, and continued expansion of consumer demands threaten to neutralize gains achieved through technological advances. Numerous studies of HEC have identified a strong positive correlation between energy consumption and income, but tend to be quiet about what implications this correlation in itself may have for policy making. Acknowledging the large increase in HEC with rising income, the author would call on central and local governments in China to consider imposing constraints on the promotion of consumerism by the mass media and advertising industry.

On a global level, pursuits of economic growth throughout the world, a world where resource endowments are limited and technological progress ultimately will be limited by the laws of physics, cannot be sustained forever. Thus, the recognition that purely technological approaches will not be sufficient may only be the first step on the way to a final recognition that a genuinely sustainable lifestyle that is replicable across the whole globe also involves limitations on consumption level. In any case, the question of what will be sufficient may not be the right question to ask. Instead we should ask what is desirable. There is evidence that "over time and across OECD countries rises in aggregate income are not associated with rises in aggregate happiness…At the aggregate level, there has been no increase in reported happiness over the last 50 years in the US and Japan, nor in Europe since 1973 since the records began" (Layard 2005). It can be argued that other trends in the OECD countries, such as more congested traffic and a perception of decreased employment security, may have offset positive effects of increased income, and hence one should be reluctant to conclude that absolute income growth have not positively affected happiness and human well-being (Frank 2005). Nevertheless, there is a very real possibility that people in developed countries can consume less and still live at least as well as they have done (Jackson 2005).

So how is this relevant for China? There can be no doubt that China's economic growth needs to be encouraged and supported by the rest of the world. China is still poor by OECD standards, and pockets of extreme poverty still exist. As for the problem of anthropogenic climate change, from 1900 to 2005 the US and the EU countries accounted for more than half of cumulative global CO_2 emissions. China accounted for only 8% (IEA 2007). If there is moral obligation to consume less in the interest of the planet, the obligation is on the already developed countries, not on China. However, China's economy is currently growing at high rates, and decisions made today will affect the society for many years to come. Thinking in long terms, the option is there for China to seek out a radically different development path than that adopted by Western countries. Considering the evidence that aggregate happiness and subjective well-being has not increased in OECD countries despite remarkable income growths, it may be that the choice to seek out a less materialistic and consumerist path can be made not necessarily out of altruism, but out of a desire to create a better society for the Chinese people.

In the age of globalisation, the Western way of life is being widely imitated throughout the world. Keyfitz (1998) sees it as the American middle-class lifestyle "diffusing around the world", becoming the unquestioned ideal and norm, everywhere. With the daunting challenge of harmful anthropogenic climate change posed upon use, and the emergence of what can be seen as a global lifestyle, perhaps it is time for both developed and developing countries to come together and discuss how truly sustainable lifestyles that are replicable across the entire globe can be achieved.

5.3 Uncertainty and limitations

Without doubt, there are substantial uncertainties in the estimates of energy use presented in this report. The uncertainties themselves cannot easily be quantified, due to the complexity of the system under study and the large number of quantitative and qualitative assumptions that were made. Some uncertainties relate to fundamental challenges of input-output analysis as a tool, such as the use of domestic energy inventory for imports and the treatment of capital formation as a final demand category. The energy embodied in Chinese imports constitute 12% of the Chinese energy demand, according to one recent estimate (IEA 2007). For products imported from countries with very different technologies and energy mixes than China, assuming domestic technology will cause significant errors. Other uncertainties relate directly to the methodology and assumptions made for the specific study presented in this report, such as the combining of national input-output tables from 2002 with Beijing expenditure data from 2005, which may seem somewhat dubious, considering the rapid development of the economy and the mixed energy efficiency picture in China's industrial sector.

Changing the perspective from energy use today to energy use in the future inevitably introduces more uncertainty into the analysis. As with all predictions of the future, there are limitations to the energy projections presented in this paper. Certainly, technological innovation and improvements in energy efficiency are likely to be important parameters affecting future energy use in the society, but are not included in the projections presented in the present paper. Furthermore, while the basic assumption that households becoming more affluent will adopt the lifestyles of the already affluent households seems plausible in the short term, it is less likely to hold in the long term. It would be unrealistic to believe that the projections are able to fully represent changes in lifestyles over time. The methodological problem of input-output analysis possibly overestimating the positive correlation between energy requirements and income is also important to consider. If the energy-income relationship is overestimated, the projected HEC will be overestimated correspondingly. Noting that limitations exist, the aim of the projections is not to come up with conclusive answers about future energy use, but rather to provide some useful insights that can add to our understanding of future energy trends.

Throughout the report, HEC has been estimated for five distinct socioeconomic groups, for urban and rural areas, respectively. The division into five socioeconomic groups originates from the Chinese Survey of Consumer Expenditure (SCE), as presented in the official statistics. Obviously, the analysis in the present paper would have benefited from a higher level of disaggregation, i.e. a division of the population into more than five socioeconomic groups. For the analysis of urban households, it is highly unfortunate that the medium-low income households and the medium income households are very similar, with the total expenditure level of the latter being only 7.6% higher than that of the former. The analysis would also greatly benefit from more detailed information regarding the consumption and energy use of the high income households. In the official statistics, specific information on expenditures of the 10% wealthiest households is available on a national level, but not on a Beijing level. As the average expenditure level of the 10% wealthiest households at the national level is lower than the average expenditure level of the 20% wealthiest households in Beijing, national data could not be used as a proxy for Beijing data. For the analysis in the present paper, in particular for the projections for the future, information on the consumption and lifestyle of the 'very high' income households in Beijing would be tremendously useful, as it could have removed some of the uncertainty associated with the construction of an artificial 'very high' income group. Also highly unfortunate is the omission of the floating population from the Beijing SCE, causing the survey to be seriously biased and not representative for the entire population in Beijing.

Field work was conducted and is presented in Section 3.5. Although the field work served an important role in improving the author's knowledge and understanding of energy use and life in Beijing in general, it did not provide any direct, quantitative inputs to the calculations. Initially, the author intended to perform a survey providing quantitative inputs to the analysis. Of particular interest would then be the floating population as well as the wealthiest households in Beijing, population groups for which additional data would be useful for the analysis. However, performing a survey that could produce quantitative inputs to the analysis was hindered by practical constraints. Firstly, there was a problem of how to deal with the issue of the survey sample not being representative for the entire population. Secondly, there were language barriers, and the problem of household members perhaps being reluctant to letting the author (i.e. a stranger) into their private homes. Obviously, the author could not freely choose households to sample.

The analysis presented in this paper uses HEC as a proxy of the environmental load associated with household activities. Using energy as an indicator for environmental load has a long history. Already in 1979, Boustead and Hancock (1979) explicitly name increasing awareness of and concern for environmental problems as one of the main purposes of analysing energy use in the society. Energy accounting schemes obviously fail to represent environmental impacts caused by different energy sources. For example, no distinction is made between using 1 kWh of electricity from hydro power and using the same amount of electricity from a fossil-fired power plant. Lack of studies considering other pollutants and impacts than energy and CO_2 is an important limitation of the existing literature on household environmental impact (Hertwich 2005). The critique is legitimate. Also, there may be a danger that, partly due to some environmental impacts receiving little attention, and partly due to a fragmentation in the scientific community where different, but not necessarily independent environmental impacts are evaluated separately, the overall pressure on the environment is underestimated. There can be no doubt that there is a need for integrated assessments which takes a variety of environmental impacts into account. Still, energy use is undoubtedly at the centre of several of China's severe environmental problems (Liu and Diamond 2005), and paths to reduce the energy intensity of the society will presumably largely coincide with paths to reduce many environmental impacts, such as local air pollution and anthropogenic climate change.

6 Conclusions

This report has presented an analysis of the direct and indirect household energy consumption (HEC) in Beijing. Estimates of HEC, broken down into main consumption categories, have been presented for households at different levels of development. A strong positive correlation between HEC and income was identified. The report has elaborated on the importance of addressing consumers' indirect influences on energy use in the society in policy making. For urban residents in Beijing, the indirect influences on energy use were found to be more than three times greater than the direct influences.

Using what is known about HEC today and how the HEC varies across income groups as a basis, projections was made of HEC in urban Beijing. Mainly due to growing incomes, total HEC in urban Beijing will grow substantially in the period 2005-2015, even with overall efficiency improvements corresponding to the central government's targets. No evidence was found that a more even distribution of wealth across income groups will produce significant reductions in overall HEC. The results quantify conclusively that without strong energy intensity reductions there will be huge increases in transport related energy use in Beijing. If increasing environmental impacts from private transport in Beijing is to be avoided, it is vital that attention is focused both on producers and consumers.

A number of sources of uncertainties have been identified. Due to the significant uncertainty, the figures should be taken as rough guides to the magnitude of different types of energy use only, not as conclusive answers. Nonetheless, it is the author's opinion that the analysis has illuminated how future lifestyle changes and income growth in Beijing is likely to affect different types of energy use, and that the estimates are sufficiently accurate to serve as a basis for making some recommendations for improving the energy efficiency of the society.

Based on the findings presented in this report, the author calls on central and local governments to:

1) Further incorporate the important role of consumer behaviour and lifestyle into energy conservation policies, e.g. by stimulating to more environmentally benign consumption patterns.
2) Make strong efforts to mitigate transport related environmental problems, focusing attention both on producers and consumers.
3) Give high priority to constructing energy efficient buildings, e.g. by making efforts to secure enforcement of the energy standards for buildings.
4) Further strengthen and expand the performance standard and labelling scheme for electrical appliances.
5) Consider imposing constraints on the promotion of consumerism by the mass media and advertising industry.

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Appendix A Characteristics of sampled households

The socioeconomic groups are denoted as follows: L: Low income; ML: Medium-low income; M: Medium income; MH Medium-high income; H: High income. T denotes 'Total', i.e. the average across all income groups.

Table A-1: Characteristics of sampled urban Beijing households (2005) by socioeconomic group (BMBS 2006)

	T	L	ML	M	MH	H
Households surveyed (households)	2000	400	400	400	400	400
Household size (persons)	2.9	3.2	3.0	2.9	2.8	2.7
Annual discretionary income (yuan/capita)	17653.0	8580.9	12485.2	16062.8	20812.9	32967.7
Annual living expenditure (yuan/capita)	13244.2	7863.5	10939.0	11772.5	15813.8	21325.2

Table A-2: Characteristics of sampled rural Beijing households (2005) by socioeconomic group (BMBS 2006)

	T	L	ML	M	MH	H
Households surveyed (households)	3000	600	600	600	600	600
Household size (persons)	3.35	3.7	3.5	3.33	3.22	3.02
Annual net income (yuan/capita)	7860	3052	5233	6990	9471	16206
Annual living expenditure (yuan/capita)	5515	3296	4022	5062	6349	9573

Appendix B Expenditure data for sampled households

The socioeconomic groups are denoted as follows: L: Low income; ML: Medium-low income; M: Medium income; MH Medium-high income; H: High income. T denotes 'Total', i.e. the average across all income groups.

Table B-1: Annual living expenditures (yuan/capita) for sampled urban Beijing households (2005) by socioeconomic group and expenditure categories (BMBS 2006)

No.	Consumption category	T	L	ML	M	MH	H
	Total	13244.2	7863.5	10939.0	11772.5	15813.8	21325.2
	Food	255.6	253.6	253.6	257.9	262.1	251.3
1	Grain	30.9	28.0	30.8	33.1	32.0	31.1
2	Starches and Tubers	46.4	39.8	46.7	47.9	49.8	49.0
3	Bean and Their Products	92.7	94.1	88.9	96.5	96.4	87.4
4	Oil or Fat	534.1	476.6	537.5	562.7	558.8	544.5
5	Meat Products	115.5	103.9	111.8	120.1	117.5	127.0
6	Poultry Products	82.4	74.5	80.1	84.5	87.4	87.3
7	Eggs	174.1	138.6	157.1	180.6	190.1	212.5
8	Aquatic Products	257.7	238.2	250.5	265.5	275.5	263.2
9	Fresh Vegetable	23.6	21.2	22.9	23.6	25.1	25.7
10	Dried Vegetable	13.6	10.3	12.4	14.2	14.5	17.1
11	Vegetable Products	75.0	67.3	73.9	76.9	78.9	79.6
12	Flavouring	52.8	37.9	47.2	51.6	55.3	76.0
13	Sugar	139.1	104.7	139.4	137.8	162.2	158.5
14	Tobacco	109.1	97.5	94.7	107.9	123.3	126.3
15	Liquor	176.9	139.8	162.5	179.9	193.8	217.7
16	Beverage	216.8	161.8	198.8	229.5	239.5	267.3
17	Fresh Fruits	60.5	48.1	57.6	62.9	66.5	70.3
18	Fresh Melon	16.9	12.0	15.2	19.8	17.3	21.2
19	Dried Fruit	13.6	9.3	13.0	14.9	15.2	16.3
20	Melon and Fruits Products	72.6	53.6	72.3	73.6	76.9	90.6
21	Nuts and Kernel	422.2	338.9	402.0	430.2	460.8	498.3
22	Cake, Milk and Dairy Products	85.1	68.4	86.3	77.6	93.3	103.4
23	Others	1.0	0.2	0.7	1.1	0.7	2.1
24	Food Processing service	1147.4	599.9	955.7	1062.2	1421.1	1839.6
25	Dinning Out	13244.2	7863.5	10939.0	11772.5	15813.8	21325.2
	Clothing						
26	Clothing for Men	307.4	162.1	250.6	289.1	370.8	502.5
27	Clothing for Women	460.8	201.5	364.3	435.2	560.3	809.9
28	Clothing for Children	35.0	20.3	27.4	33.3	36.2	62.3
29	Cloth	16.8	8.7	17.3	16.8	18.0	24.9
30	Shoes	296.2	166.8	252.9	296.5	340.3	456.4
31	Others	52.5	31.4	46.9	51.8	59.6	78.0
32	Clothing Processing and servings	15.4	7.6	11.9	14.6	18.8	26.5
	Households Articles and Services						
33	Furniture	195.3	53.4	112.6	79.6	241.8	537.0
34	Household Appliances	246.7	106.0	191.9	187.7	347.1	439.9
35	Weave Ornament	12.6	2.3	7.8	6.5	10.5	39.1
36	Ornamental Lamps and Lanterns	8.7	1.9	5.3	5.4	10.7	22.5
37	Others	12.3	3.2	10.2	8.1	19.0	23.3
38	Bedding	53.6	20.4	38.1	48.9	76.8	92.6
39	Groceries for Households Daily Use	246.9	169.4	228.1	227.3	277.5	351.7
40	Furniture Materials	5.9	0.7	11.0	0.9	3.4	14.6
41	Households Services	70.2	25.5	50.3	73.1	73.0	140.7
	Medicine and Medical Services						
42	Medical Apparatus	10.2	3.6	6.4	7.1	10.3	25.5
43	Health Care Apparatus	35.5	14.3	14.2	54.7	53.4	46.7
44	Medicine Expenses	640.9	460.0	613.4	690.0	775.0	702.1
45	Tonic	217.7	78.0	184.3	206.5	308.9	343.7
46	Medical Services	378.5	198.8	339.7	388.0	576.1	429.2

47	Others	13.0	3.2	7.7	17.2	20.9	18.2
	Transportation and Communication						
48	Means of Transport for Household	499.0	56.5	179.3	25.4	813.9	1582.3
49	Fuels and Parts	135.5	31.4	48.2	72.1	146.2	416.9
50	Means of Transport Services Expense	127.3	27.4	33.4	47.3	150.9	416.0
51	Transport Fare	338.9	162.0	252.3	306.4	415.6	607.6
52	Communication Facility	172.2	72.8	166.7	158.9	206.3	278.3
53	Communication Service	670.6	450.6	585.8	678.7	800.9	891.8
	Education, Culture, Recreation Services						
54	Cultural and Recreational Articles	677.5	299.9	575.7	607.4	744.1	1256.0
55	Cultural and Recreation Services	584.4	182.7	393.5	468.1	699.0	1294.5
56	Teaching material	52.5	56.2	62.6	46.8	46.0	49.3
57	Nonbligation Tuition	285.5	308.0	327.6	315.9	266.3	198.0
58	Tuition	102.5	107.6	117.7	80.3	97.8	107.8
59	Tuition of Adult Education	168.0	117.1	117.9	144.7	251.6	226.6
60	Family Education Expenses	28.8	22.3	31.2	23.0	37.2	31.4
61	Educate	123.9	88.2	124.5	109.7	128.2	177.2
62	Put up School	23.9	18.5	29.7	19.6	34.6	17.6
63	Others	83.5	38.4	22.0	64.6	97.1	214.1
	Residence						
64	Construction Materials	87.8	99.4	78.0	72.8	85.6	103.1
65	Rent	313.2	60.6	141.3	95.7	473.5	882.9
66	Repairs	53.2	27.3	35.5	34.0	89.6	87.9
67	Others	2.1	1.0	1.5	0.7	5.5	2.3
68	Water	92.2	73.5	87.5	85.8	102.5	116.3
69	Electricity	252.5	189.9	225.6	253.8	273.4	335.9
70	Coal	22.6	27.2	33.9	18.9	13.2	17.6
71	Liquefied Petroleum Gas	17.1	19.5	17.2	16.8	16.7	14.8
72	Pipeline Gas	98.4	79.6	92.6	93.0	102.7	129.4
73	Others Fuel	0.5	0.1	1.1	0.4	0.4	0.5
74	Others	44.4	16.1	18.7	25.4	53.8	118.6
75	Habitation Service Charge	55.8	17.5	32.7	24.8	77.6	139.3
	Miscellaneous Commodities and Services						
76	Miscellaneous Commodities	335.0	164.2	248.4	286.4	408.7	616.7
77	Services	191.6	58.9	87.7	184.3	198.4	471.4

In Table B-2, some minor changes were made to the original presentation in the Beijing Statistical Yearbook. No alterations were made to the actual expenditure numbers.

Table B-2: Annual living expenditures (yuan/capita) for sampled rural Beijing households (2005) by socioeconomic group and expenditure categories (BMBS 2006)

No.	Category	T	L	ML	M	MH	H
	Total	5515	3296	4022	5062	6349	9573
1	**Food Expenditure (other)**	872	501	668	833	1044	1421
2	Staple Food	219	203	196	213	221	268
3	Non-Staple Food	716	482	613	700	868	978
4	**Clothing Expenditure (other)**	163	87	121	150	200	283
5	Garments	265	104	168	229	347	526
6	**Residence (other)**	206	107	133	175	239	408
7	Housing	388	244	145	317	436	876
8	Fuels	300	202	262	297	369	393
9	**Household Facilities, Articles and| Services (other)**	14	7	10	19	14	21
10	Durable Consumer Goods	205	97	91	110	135	217
11	Daily Use Household Articles	122	71	129	150	246	443
12	**Medicines and Medical Services**	499	335	388	456	571	801
13	**Transportation and Communications (other)**	191	100	123	136	234	392
14	Transportation Means	93	26	37	65	98	267
15	Transportation	72	26	58	56	81	152
16	Posts and Telecommunications	250	130	169	229	299	462
17	**Cultural, Education and Recreation**	134	71	84	108	149	285

	Articles and Services (other)						
18	Mechanical and Electric Consumer Goods of Culture and Recreation	131	60	70	91	126	335
19	Books, Newspapers and Magazines	17	10	15	18	18	27
20	Tuition and Incidentals	479	357	435	566	453	609
21	Recreation	74	26	34	57	83	190
22	**Other Commodity and Services (other)**	61	28	40	49	79	122
23	Commodity Expenditures	44	22	33	38	39	97

Appendix C Details concerning the results

The socioeconomic groups are denoted as follows: L: Low income; ML: Medium-low income; M: Medium income; MH Medium-high income; H: High income; VH: Very high income. T denotes 'Total', i.e. the average across all income groups from L to H (excluding VH).

Table C-1: Annual urban HEC (GJ/capita) in 2005 by socioeconomic group and expenditure categories

No.	Consumption category	T	L	ML	M	MH	H	VH
	Total	46.39	28.53	37.83	40.05	53.23	77.41	189.84
	Food	0.60	0.59	0.59	0.60	0.61	0.59	0.70
1	Grain	0.07	0.07	0.07	0.08	0.07	0.07	0.09
2	Starches and Tubers	0.11	0.10	0.11	0.12	0.12	0.12	0.14
3	Bean and Their Products	0.21	0.21	0.20	0.22	0.22	0.20	0.24
4	Oil or Fat	1.05	0.93	1.05	1.10	1.10	1.07	1.27
5	Meat Products	0.23	0.20	0.22	0.24	0.23	0.25	0.30
6	Poultry Products	0.16	0.15	0.16	0.17	0.17	0.17	0.20
7	Eggs	0.36	0.29	0.32	0.37	0.39	0.44	0.52
8	Aquatic Products	0.63	0.58	0.61	0.65	0.67	0.64	0.77
9	Fresh Vegetable	0.06	0.05	0.06	0.06	0.06	0.06	0.07
10	Dried Vegetable	0.03	0.03	0.03	0.03	0.04	0.04	0.05
11	Vegetable Products	0.21	0.19	0.21	0.22	0.22	0.22	0.27
12	Flavouring	0.14	0.10	0.12	0.14	0.15	0.20	0.24
13	Sugar	0.12	0.09	0.12	0.12	0.14	0.14	0.16
14	Tobacco	0.29	0.26	0.25	0.29	0.33	0.34	0.40
15	Liquor	0.43	0.34	0.40	0.44	0.47	0.53	0.63
16	Beverage	0.53	0.40	0.49	0.56	0.59	0.65	0.78
17	Fresh Fruits	0.15	0.12	0.14	0.15	0.16	0.17	0.20
18	Fresh Melon	0.04	0.03	0.04	0.05	0.04	0.05	0.06
19	Dried Fruit	0.03	0.02	0.03	0.04	0.04	0.04	0.05
20	Melon and Fruits Products	0.18	0.13	0.18	0.18	0.19	0.22	0.26
21	Nuts and Kernel	1.19	0.96	1.13	1.21	1.30	1.40	1.67
22	Cake, Milk and Dairy Products	0.24	0.19	0.24	0.22	0.26	0.29	0.35
23	Others	0.00	0.00	0.00	0.00	0.00	0.01	0.01
24	Food Processing service	2.14	1.12	1.78	1.98	2.65	3.43	4.07
25	Dinning Out	0.60	0.59	0.59	0.60	0.61	0.59	0.70
	Clothing							
26	Clothing for Men	0.85	0.45	0.69	0.80	1.02	1.38	4.83
27	Clothing for Women	1.27	0.55	1.00	1.20	1.54	2.23	7.78
28	Clothing for Children	0.10	0.06	0.08	0.09	0.10	0.17	0.60
29	Cloth	0.05	0.03	0.06	0.05	0.06	0.08	0.28
30	Shoes	0.95	0.53	0.81	0.95	1.09	1.46	5.10
31	Others	0.17	0.10	0.15	0.17	0.19	0.25	0.87
32	Clothing Processing and servings	0.05	0.02	0.04	0.05	0.06	0.09	0.30
	Households Articles and Services							
33	Furniture	0.58	0.16	0.33	0.24	0.72	1.59	5.55
34	Household Appliances	0.82	0.35	0.64	0.62	1.15	1.46	5.10
35	Weave Ornament	0.04	0.01	0.02	0.02	0.03	0.11	0.38
36	Ornamental Lamps and Lanterns	0.03	0.01	0.02	0.02	0.04	0.08	0.28
37	Others	0.04	0.01	0.04	0.03	0.07	0.08	0.29
38	Bedding	0.16	0.06	0.11	0.14	0.23	0.27	0.96
39	Groceries for Households Daily Use	0.78	0.53	0.72	0.71	0.87	1.11	3.86
40	Furniture Materials	0.02	0.00	0.03	0.00	0.01	0.04	0.15
41	Households Services	0.15	0.06	0.11	0.16	0.16	0.31	1.07
	Medicine and Medical Services							
42	Medical Apparatus	0.03	0.01	0.02	0.02	0.03	0.07	0.09
43	Health Care Apparatus	0.10	0.04	0.04	0.16	0.15	0.13	0.16
44	Medicine Expenses	1.85	1.33	1.77	1.99	2.24	2.03	2.46
45	Tonic	0.63	0.22	0.53	0.60	0.89	0.99	1.20
46	Medical Services	0.73	0.38	0.66	0.75	1.11	0.83	1.01

47	Others	0.04	0.01	0.02	0.05	0.06	0.05	0.06
	Transportation and Communication							
48	Means of Transport for Household	1.66	0.19	0.60	0.08	2.71	5.27	14.31
49	Fuels and Parts	0.78	0.18	0.28	0.42	0.85	2.41	6.56
50	Means of Transport Services Expense	0.24	0.05	0.06	0.09	0.28	0.78	2.11
51	Transport Fare	1.42	0.68	1.06	1.29	1.75	2.55	6.94
52	Communication Facility	0.41	0.17	0.40	0.38	0.50	0.67	0.86
53	Communication Service	1.51	1.01	1.32	1.53	1.80	2.01	2.57
	Education, Culture, Recreation Services							
54	Cultural and Recreational Articles	2.15	0.95	1.83	1.93	2.36	3.98	12.34
55	Cultural and Recreation Services	1.09	0.34	0.73	0.87	1.30	2.41	7.47
56	Teaching material	0.22	0.24	0.26	0.20	0.19	0.21	0.24
57	Nonbligation Tuition	0.58	0.63	0.67	0.65	0.54	0.40	0.48
58	Tuition	0.21	0.22	0.24	0.16	0.20	0.22	0.26
59	Tuition of Adult Education	0.34	0.24	0.24	0.30	0.51	0.46	0.54
60	Family Education Expenses	0.06	0.05	0.06	0.05	0.08	0.06	0.08
61	Educate	0.25	0.18	0.25	0.22	0.26	0.36	0.43
62	Put up School	0.05	0.04	0.06	0.04	0.07	0.04	0.04
63	Others	0.17	0.08	0.05	0.13	0.20	0.44	0.51
	Residence							
64	Construction Materials	0.51	0.57	0.45	0.42	0.49	0.59	1.49
65	Rent	0.34	0.06	0.15	0.10	0.51	0.95	2.37
66	Repairs	0.12	0.06	0.08	0.08	0.21	0.20	0.51
67	Others	0.00	0.00	0.00	0.00	0.01	0.00	0.01
68	Water	0.50	0.40	0.47	0.46	0.55	0.63	1.50
69	Electricity	0.65	0.49	0.58	0.65	0.70	0.87	2.07
70	Coal	0.10	0.12	0.15	0.09	0.06	0.08	0.19
71	Liquefied Petroleum Gas	0.11	0.12	0.11	0.11	0.11	0.09	0.22
72	Pipeline Gas	0.65	0.52	0.61	0.61	0.68	0.85	2.03
73	Others Fuel	0.00	0.00	0.01	0.00	0.00	0.00	0.01
74	Others	0.32	0.11	0.13	0.18	0.38	0.84	2.01
75	Habitation Service Charge	0.13	0.04	0.08	0.06	0.18	0.33	0.82
	Miscellaneous Commodities and Services							
76	Miscellaneous Commodities	1.64	0.80	1.21	1.40	2.00	3.01	18.26
77	Services	0.44	0.14	0.20	0.43	0.46	1.09	6.60
	Direct							
1	Electricity	1.98	1.57	1.82	1.96	2.17	2.45	3.30
2	Coal	1.03	1.25	1.56	0.87	0.61	0.81	0.40
3	Liquified Petroleum Gas	1.13	1.29	1.14	1.11	1.11	0.98	0.60
4	Natural gas	1.71	1.38	1.61	1.62	1.78	2.25	3.20
5	Others fuel	0.04	0.01	0.10	0.04	0.04	0.04	0.04
6	Central heat (steam)	1.55	1.41	1.51	1.56	1.61	1.67	2.10
7	Gasoline and diesel oil	3.67	0.84	1.30	1.94	3.94	11.22	30.51
8	Biogas	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	Stalks	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Firewood	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Some of the results in Chapter 4 are presented by main (aggregated) consumption categories. With reference to the category numbers in Table C-1, the urban aggregated categories were defined as shown in Table C-2.

Table C-2 Aggregated urban consumption categories

Aggregated category title	Direct energy use	Indirect energy use
Electricity, heat and household fuels	Nos. 1-6	
Fuel for transport	Nos. 7-8	
Food and beverages		Nos. 1-25
Clothing and footwear		Nos. 26-32

Transport (excluding fuels)		Nos. 48-51
Communucations		Nos. 52-53
Household articles and services		Nos. 33-41
Residence (excl. energy use in households)		Nos. 64-75
Medicine and medical services		Nos. 42-47
Culture and recreation		Nos. 54-55
Education		Nos. 56-63
Miscellaneous		Nos. 76-77

Table C-3: Annual rural HEC (GJ/capita) in 2005 by socioeconomic group and expenditure categories

No.	Category	T	L	ML	M	MH	H
	Total (excluding biomass)	35.09	21.45	27.75	32.74	41.61	55.86
1	**Food Expenditure (other)**	1.17	1.56	1.95	2.44	3.32	1.17
2	Staple Food	0.45	0.44	0.47	0.49	0.59	0.45
3	Non-Staple Food	1.08	1.38	1.57	1.95	2.20	1.08
4	**Clothing Expenditure (other)**	0.27	0.38	0.47	0.63	0.89	0.27
5	Garments	0.29	0.47	0.64	0.97	1.47	0.29
6	**Residence (other)**	0.82	1.01	1.34	1.82	3.11	0.82
7	Housing	0.59	0.35	0.76	1.05	2.11	0.59
8	Fuels	1.11	1.45	1.64	2.04	2.17	1.11
9	**Household Facilities, Articles and| Services (other)**	0.02	0.03	0.05	0.04	0.05	0.02
10	Durable Consumer Goods	0.31	0.29	0.35	0.43	0.69	0.31
11	Daily Use Household Articles	0.22	0.40	0.46	0.76	1.37	0.22
12	**Medicines and Medical Services**	0.86	1.00	1.17	1.46	2.05	0.86
13	**Transportation and Communications (other)**	0.35	0.43	0.48	0.82	1.37	0.35
14	Transportation Means	0.09	0.12	0.21	0.32	0.88	0.09
15	Transportation	0.14	0.31	0.30	0.43	0.81	0.14
16	Posts and Telecommunications	0.29	0.38	0.51	0.67	1.04	0.29
17	**Cultural, Education and Recreation Articles and Services (other)**	0.18	0.22	0.28	0.38	0.73	0.18
18	Mechanical and Electric Consumer Goods of Culture and Recreation	0.20	0.24	0.31	0.43	1.14	0.20
19	Books, Newspapers and Magazines	0.04	0.06	0.07	0.07	0.11	0.04
20	Tuition and Incidentals	0.73	0.89	1.16	0.93	1.25	0.73
21	Recreation	0.06	0.08	0.13	0.19	0.43	0.06
22	**Other Commodity and Services (other)**	0.07	0.11	0.13	0.21	0.33	0.07
23	Commodity Expenditures	0.08	0.12	0.13	0.14	0.34	0.08
	Direct						
1	Electricity	2.61	1.56	1.90	2.33	3.01	4.60
2	Coal	14.09	9.49	12.31	13.95	17.34	18.46
3	Liquified Petroleum Gas	0.52	0.35	0.45	0.51	0.64	0.68
4	Natural gas	0.00	0.00	0.00	0.00	0.00	0.00
5	Others fuel	0.00	0.00	0.00	0.00	0.00	0.00
6	Central heat (steam)	0.00	0.00	0.00	0.00	0.00	0.00
7	Gasoline and diesel oil	1.73	0.63	1.40	1.35	1.95	3.66
8	Biogas	0.07	0.07	0.07	0.07	0.07	0.07
9	Stalks	5.67	5.67	5.67	5.67	5.67	5.67
10	Firewood	2.40	2.40	2.40	2.40	2.40	2.40

With reference to the category numbers in Table C-3, the rural aggregated categories were defined as shown in Table C-4.

Table C-4 Aggregated rural consumption categories

Aggregated category title	Direct energy use	Indirect energy use
Electricity and household fuels (excl. biomass)	Nos. 1-6	
Fuel for transport	Nos. 7-8	
Food and beverages		Nos. 1-3

Clothing and footwear		Nos. 4-5
Transport (excl. fuels) and communications		Nos. 13-16
Household articles and services		Nos. 9-11
Residence (excl. energy use in households)		Nos. 6-8
Medicine and medical services		Nos. 12
Education, culture and recreation		Nos. 17-21
Miscellaneous		Nos. 22-23
Biomass	Nos. 9-10	

Appendix D Details concerning the energy projections

D.1 Projected growth in total expenditure level

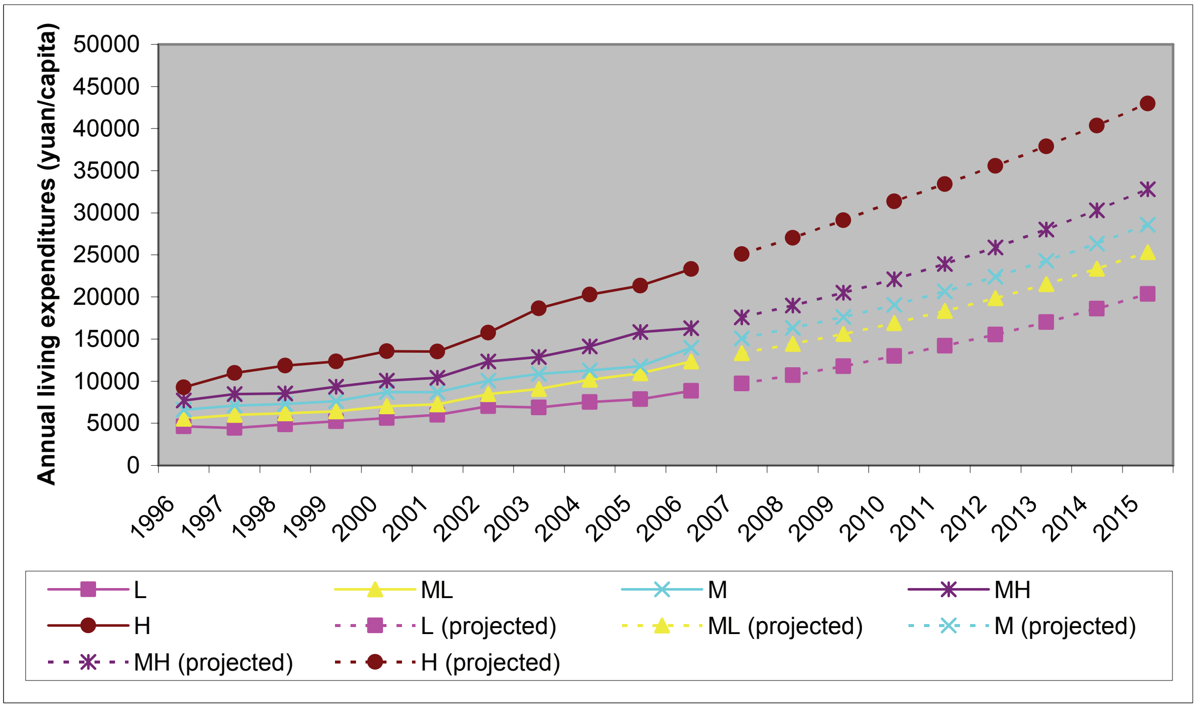

Figure D-1: Historical and projected growth in annual living expenditures (yuan/capita) in urban Beijing in Scenario 1 (even distribution of wealth)

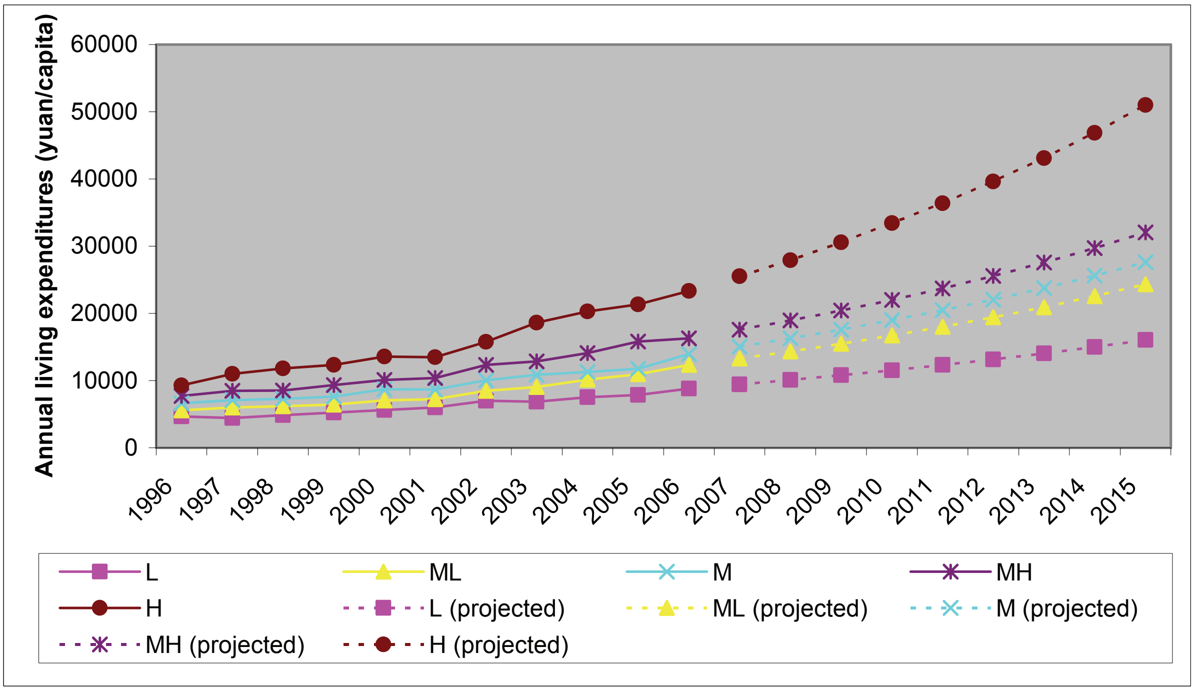

Figure D-2: Historical and projected growth in annual living expenditures (yuan/capita) in urban Beijing in Scenario 2 (uneven distribution of wealth)

D.2 Characteristics of the very high income households

Some studies of household energy consumption (HEC) in developed countries have shown that while the indirect HEC increases steadily with rising income, direct HEC tends to flatten out (Hertwich 2005). The results presented in Section 4.1, indicating a strong positive correlation between consumption of fuel for transport and income, suggest that at this point in time this conclusion is not valid for urban Beijing. Evidence from developed countries show that the share of available income spent on transport increases with income until it stabilises at 10-16%. The one exception to this rule is Japan, where the share spent on transport has stabilised at about 8%, reflecting the dense population and more developed public transport systems (Schafer and Victor 2000; WBCSD 2001). The high-income households in Beijing spend 9.2% of their income on transport, and thus this particular population group is drawing near the overall saturation level found in developed countries. It is impossible to predict, though, exactly at what level there will be saturation. The assumption was made that the very-high income households spend 11.5% of their disposable income on transport. In the two scenarios, this is equivalent to the entire population spending on average 10.8% and 11.0% of their income on transport. Assuming that the ratio between disposable income and total expenditure level for the very-high income households is 1.4[10], this implies that the expenditures on transport amount to about 8200 yuan/capita. This means that the very-high income households' expenditures on transport are 2.72 times greater than the expenditures of the high-income households. Consequently, the direct energy use related to transport for the very-high income group was determined by multiplying the consumption of the high income group with a factor 2.72. Figure D-3 shows the use of fuels for transport versus total expenditure level, including the extrapolated data for the very-high income group. The curve in Figure D-3, as well as all curves in subsequent figures of the present section, has six asterisks, one for each socioeconomic group.

Turning the attention to direct energy use in households, it is again referred to the results presented in Section 4.1. The total direct energy use in households varies relatively little with income, with the high-income households consuming only 18.7% more per capita than the low-income households. Moving across income levels, there is a substitution from lower-quality energy sources (coal and bottled LPG) to higher-quality energy sources (heat, electricity, piped natural gas). Similar transitions from coal and petroleum products towards electricity, heat and pipeline gas have occurred over time in developed countries, as identified e.g. by Vringer and Blok (2000) for Holland and Park and Heo (2007) for South Korea. The assumption was made that when moving up in income towards very-high income level, there will be a continued modest increase in total household energy use and a continued shift in energy carriers towards electricity, heat and natural gas. The extrapolation of household energy trends was made as shown in Figure D-4.

As for electricity, ownership of refrigerators and clothes washers in urban Beijing households seems to have reached saturation (Figure 2-17). With a further increase in income, exceeding the upper end of the scale in Figure 2-17, a slightly higher penetration level can be expected for colour televisions and the energy intensive appliances air conditioner and freezer. Judging from data on appliance ownership across income levels (BMBS 2006), moving from the high-income household group to the very-high income household group will bring about modest but significantly higher penetration levels of a number of minor electrical appliances that are

[10] The ratio is 1.4 for the medium income households, 1.3 for the medium-high income households and 1.5 for the high income households

not included in Figure 2-17, such as electrical cooking appliances, vacuum cleaners, computers and hi-fi systems. In this perspective, it was considered that the extrapolation of electricity use as shown in Figure D-4 is sensible.

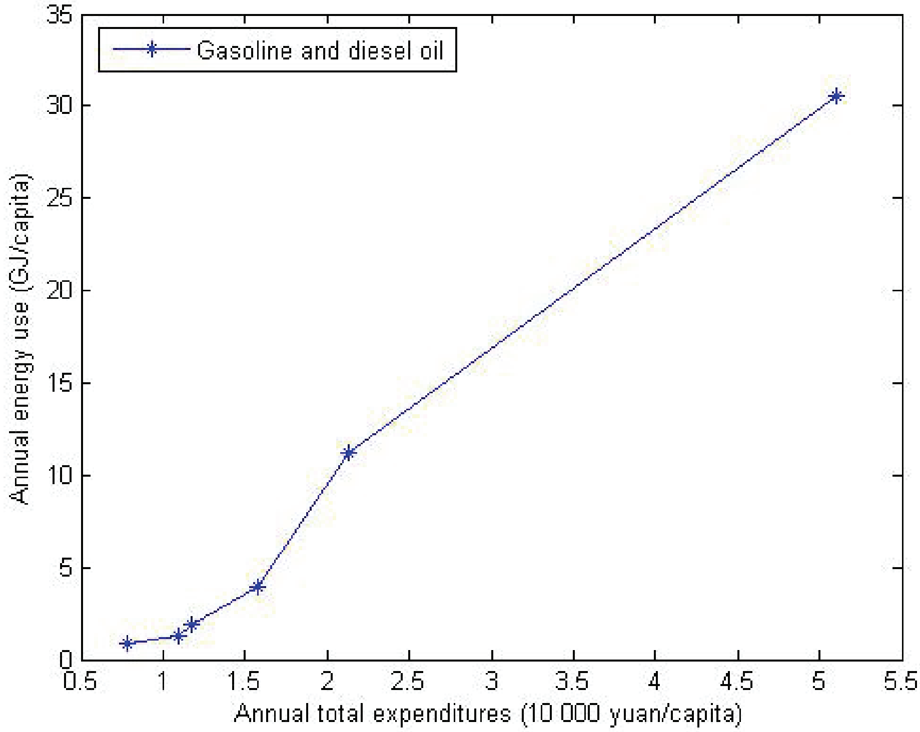

Figure D-3: Annual direct energy use for transport (GJ/capita) versus annual total expenditure level (GJ/capita) (extrapolated)

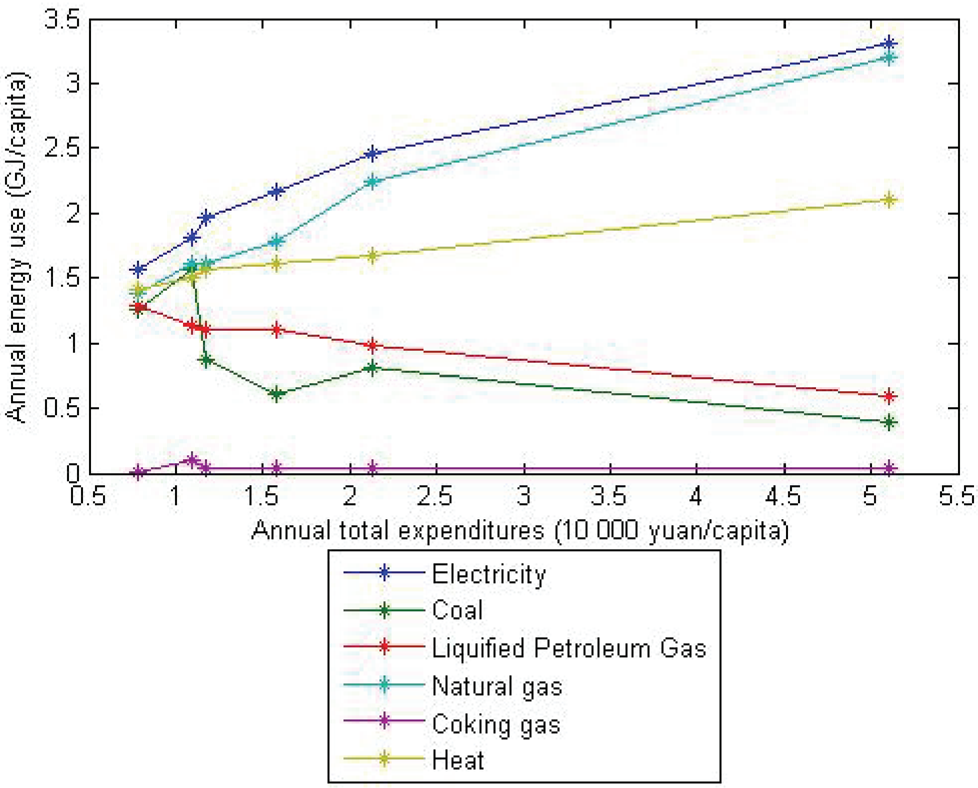

Figure D-4: Annual direct energy use in households (GJ/capita) versus annual total expenditure level (GJ/capita) (extrapolated)

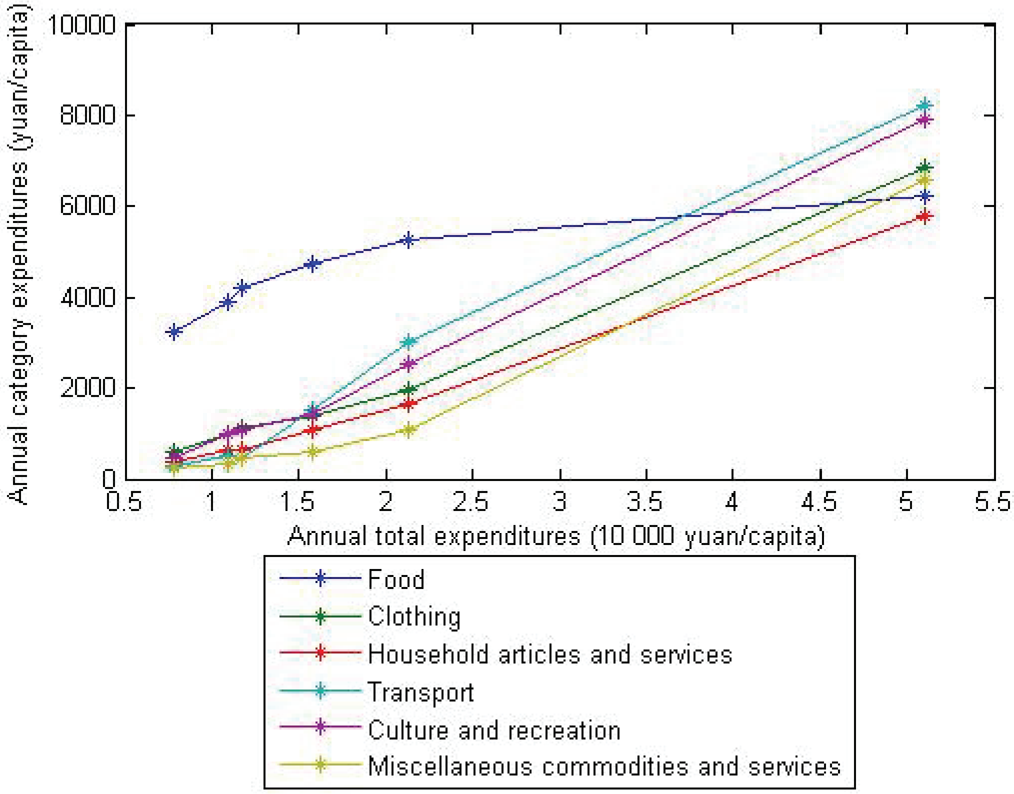

Figure D-5: Annual category expenditures (yuan/capita) by annual total expenditure level (yuan/capita) (extrapolated)

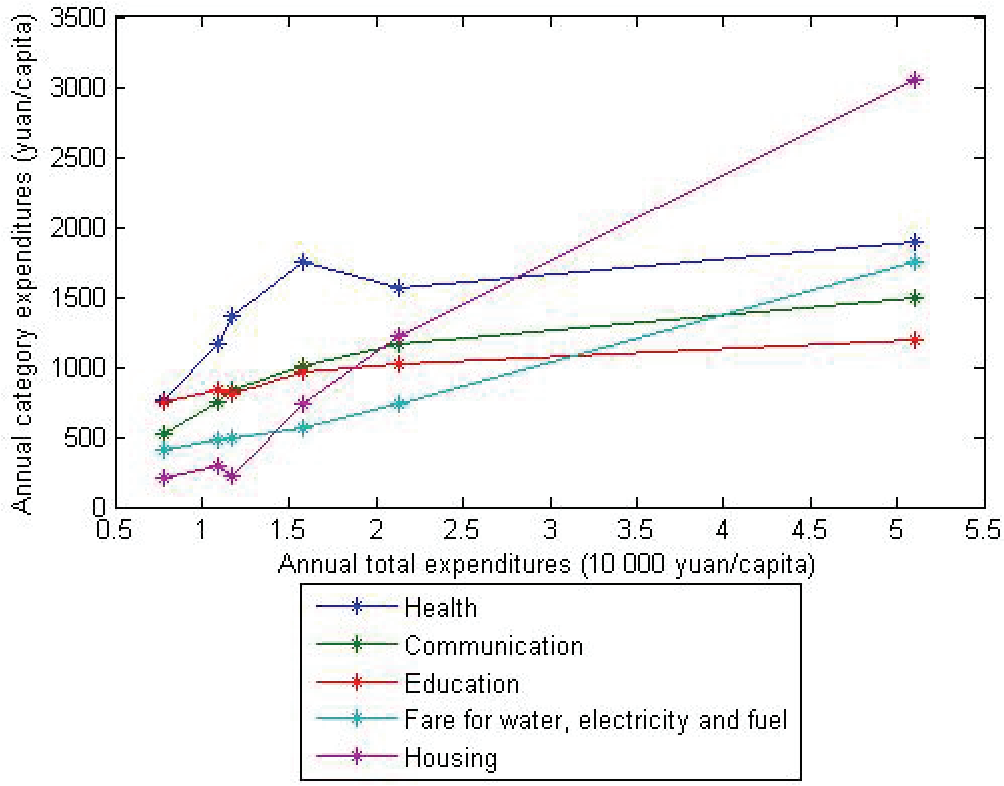

Figure D-6: Annual category expenditures (yuan/capita) by annual total expenditure level (yuan/capita) (extrapolated)

Determining the indirect energy requirements of the very-high income households required data on category specific expenditures for this group. Assessing all 77 expenditure categories would be a too laborious task. Instead, the 77 expenditure categories were aggregated into 11 categories[11]. For each of the aggregated categories, expenditure trends were extrapolated to also cover the total expenditure level for the very high income group. The extrapolation was made as shown in Figures D-5 and D-6. Further, the assumption was made that the distribution of expenditures within one aggregated category is the same for the very-high income households as for the high income households. For example, ‘grain’ constitutes 4.8% of the high income households’ expenditures on the aggregated category ‘food’. Therefore, the assumption is made that ‘grain’ constitutes 4.8% of the very-high income households’ expenditures ‘food’. Thus, the share of expenditure on ‘grain’ to total expenditures on ‘food’ is the same for the high and very-high income households, but the total (absolute) expenditures on ‘food’ is different.

As noted previously in the present section, the very high income households’ total expenditures on transport were set to 8200 yuan/capita. For most of the consumption categories, expenditures were assumed to continue to rise with income, at varying rates. Expenditures on ‘Food’, ‘Health’ and ‘Education’ were assumed to increase at relatively low rates.

[11] Note that the consumption categories are defined slightly differently here, compared to the categories that are used in Chapter 4.

Appendix E Excursions

E.1 Questionnaire for class visit

QUESTIONNAIRE

1. Household details

Number of household members: _____ (please fill in number)

Type of housing: - Single family detached
(please mark one answer) - Single family attached
- 7 stories or below
- 8 stories or above
- Other
- Don't know

2. What sources of energy does your household use for…? (please mark one or more answers in each column)

	Cooking	**Indoor heating**	**Water heating**
Bottled gas			
Gas from pipes			
Coal			
Electricity			
District heating (steam)			
Other			
Don't know			

3. How many of the following goods are owned by your household? (please fill in the appropriate number in each row)

Good	**Number**
Refrigerator	
Air conditioner	
Television	
Clothes washer	
Computer	
Freezer	
Electric cooking appliances	
Dishwasher	
Car	

4. If you were to buy a refrigerator, which attributes do you think you would look for? (please fill in the appropriate number when 1=lowest priority, 4= highest priority).

Attribute:	Volume	Energy use	Design	Price	Other
Priority:					

5. How often are the following goods used by any household member? (please fill in the appropriate number in each row)

	Clothes washer	**Dishwasher**
0-2 times a week		
3-6 times a week		
More than 6 times a week		

Don’t know/Don’t own		

6. How concerned are you about…? (please set one mark in each row)

	Not concerned	Quite concerned	Very concerned	Don’t know
Local air pollution				
Safe energy supply				
Safe water supply				
Climate change impacts				

7. When you are going to and from school, how convenient do you think it is to use the..? (please set one mark in each row)

	Not convenient	Quite convenient	Very convenient	Don’t know
Bus				
Subway				

8. How often du you turn off the lights when you are leaving a room? (please mark one answer)

- Never
- Sometimes
- Usually
- Always
- Don’t know

9. What do you wish that your household would spend more money on? (please set up to three marks)

- Household articles
- Clothing
- Medical articles and services
- Food
- Transport
- Leisure activities
- Other?

Optional: I am interested in what you think. If you have any other comments or views, please write here:

Thank you very much!

E.2 Schedule for household interviews

A Household characteristics and ownership
Questions:

1) What is the number of household members? (most likely three)
2) What is the total annual household income?
3) What is the dwelling’s total living area (square metres)?
4) How many rooms are there?

B Heating/cooling

Observe:

- The heating equipment. What types of heating equipments are there? Where is the equipment placed?

Questions:

1) How is the indoor space heated? Do you have a choice in means of heating?
2) Do you have a heat pump that can be used both for heating and cooling?
3) How is the indoor temperature regulated in the winter?
4) How is it regulated in the summer?
5) Is the indoor temperature kept the same in all rooms?
6) Is the indoor temperature kept constant during the whole day (also during night and when no one is home)?
7) What is the typical indoor temperature in the winter?
8) On warm summer days, do you think your equipment provides sufficient cooling?
9) How is water heated? What is the energy source? Do several apartments share one heater?
10) What is the price of central heating and gas used for heating?
11) Do you worry about the costs associated with heating in the winter?
12) Do you worry about the costs associated with cooling in the summer?

C Cooking

Observe:

- The cooking equipment. What types of appliances are there on gas and on electricity? To what extend are the appliances comparable in size and type to appliances typically found in Western households?
- Placing of refrigerator. Is it placed next to a heat source?

Questions:

1) How often is the different cooking equipment used at home?
2) How often do you eat out? Do they think this is common also for other households?

D Electrical appliances and lighting

Observe:

- Lighting. What type of light sources are there and where they are placed?
- Type and number of various electrical appliances. Intuitively, does it seem comparable to what one would typically see in a Western household?

Questions:

1) Would you look for an energy label if they were to buy a refrigerator?
2) Do you worry about the costs of electricity use (when using appliances like clothes washer or electrical heated water)?
3) Are you aware of that some appliances use electricity even when they are not in use?
4) How much do you pay for electricity each year?
5) Do you sometimes leave the television on even when no one is watching?

E Transport

Questions:

1) When did you buy the car?
2) How much does your household spend on transport fuel each month?
3) What are the typical purposes of car trips (job, school, leisure, …)?
4) Do you often combine several purposes for one trip? If so, what kinds of purposes are typically combined?
5) Approximately how much time do you (car drivers) spend in the car each day?
6) If the household does not own a car: Do you plan to buy one?
7) How many times a week do household members use the subway? How many times a week do household members use the bus?
8) What are your opinions on the public transport system?
9) How much money do you spend on taxi each month? Do you think this is common also for other households?
10) What is you opinion on the traffic? What do you think it will be like in the future?
11) In the past two years, how many times have you travelled with airplane?

F Additional questions

1) Do you worry about the pollution? Have they noticed any improvement in the past years or has it gotten worse?

Appendix F Electronic attachment

Key files for the calculations are included in an electronic attachment. In total, the attachment includes 14 files that were used in the calculations. The main calculation procedures should be visible in the files. For more information about the specific files, it is referred to the additional file ‘Readme.pdf’, which contains a brief description of each of the files that were used in the calculations.