HOUSEHOLD ENERGY CONSUMPTION IN CHINA: 1987-2007

by

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ABSTRACT OF THE DISSERTATION

Household Energy Consumption in China: 1987-2007

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This dissertation examines the trends of household energy consumption in China during two recent decades and explores socio-economic factors, such as household wealth, urbanization, and lifestyle changes, that influenced the changes. At the national and multi-regional level, *structural decomposition analysis* of *input-output tables* is used to calculate and analyze indirect energy use for urban and rural households. This approach enables examination of the influence of key macroeconomic factors of the changes in household indirect energy consumption in a shift share fashion. At the household level, this dissertation contrasts the lifestyles of urban households, rural households, and rural-to-urban migrants based on survey data from the *Chinese Household Income Projects*. The *consumer lifestyle approach* is used to link household indirect energy use to household expenditures and *multivariate analysis* is used to explore key factors affecting indirect energy use at the household level.

Structural decomposition analysis indicates that household consumption mainly drove the rise of indirect energy use while energy efficiency improvements in production technology offset most of the increment. Population growth and urbanization played an important role in driving up indirect energy use between 1987 and 2007. Rapid urbanization and population migration from hinterland to coastal regions contributed heavily to regional differences in the rise of household indirect energy use across China. At the household level, household indirect energy use is affected in a statistically significant manner by climate, income, household size, and housing floor area.

Several policy recommendations follow from this. First, China should further encourage renewable energy and promote clean-coal technologies in electric power generation. This is particularly important as household move from coal and other fuels toward electricity usage. For space heating, China should gradually switch from coal to natural gas and liberalize its central heating market. Second, China should adopt stringent energy efficiency standards for home appliances and promote highly efficient products by labeling, offering subsidies, tax credits, or low interest loans to households to encourage their use. Last, China seriously needs to consider securing a supply of energy that is sufficient to meet it rapidly rising household demand for energy.

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Chapter 1

Introduction

1.1 Introduction

Energy is an engine of economic growth. Energy security and availability have long been hot topics in world political scene (Andrews, 2006). Unfortunately, energy is a main contributor to air pollution and, hence, global climate change. An international dilemma is finding a balance among economic growth, energy security, and environmental protection across nations. It is particularly perplexing set of issues for developing countries.

China is the largest developing country in the world. During the past three decades, it has enjoyed near double-digit annual economic growth. To support such rapid economic growth, China's energy consumption has increased fivefold from 603 million tons of coal equivalent (Mtce) in 1980 to over 3 billion tce in 2009 (National Bureau of Statistics of China (NBS), 2010). In 2009, the nation consumed 17.3% of the world's energy compared to 7.9% in 1973, making it the world's largest energy consumer and top greenhouse gas emitter. According to the International Energy Agency (IEA, 2010), China's share is expected to surge by 22% through 2035. Despite being the largest energy consumer, China's energy consumption *per capita* was only 1.6 tce in 2008, about a third of the OECD average (IEA, 2010). Given China's low consumption per-capita and its huge population size, the potential for China's future energy consumption growth looms large.

Since 1993, China has been a net energy importing country. In 2009, it was the second largest importer of oil. Imports accounted for about two thirds of the nation's total oil consumption (NBS, 2010). China has also been a net importer of liquefied petroleum gas (LPG) and natural gas. In 2009, its imports accounted for 19% and

8.5% of LPG and natural gas consumption, respectively. In the 12^{th} Five Year Plan (FYP, 2010-2015), China cited a desire to increase the share of natural gas among all fuels it consumes from 3.8% in 2008 to 8.3% in 2015. Hence it is expected that China will rely increasingly on imported gas (IEA, 2011). Perhaps more surprisingly, due to its own large set of reserves, China also has emerged as a coal importer in 2009. Clearly, energy security is becoming an ever larger issue in China. Indeed, the IEA (2011) has forecasted that China will account for over 30% of the projected growth in global energy demand.

China is a developing country that relies heavily on its booming industrial sector. During the past three decades, its economic growth has been driven by capital investment and exports (see in Figure 1.1). The role of household spending decreased from 50.8% in 1980 to 33.8% in 2010. Compared with other countries, China GDP share of household consumption is quite low (see *Figure* 1.2). In 2009, household consumption accounted for only 35.6% of GDP in China, but as much as 71.1% in the USA and 57.5% in India (OECD, 2013).

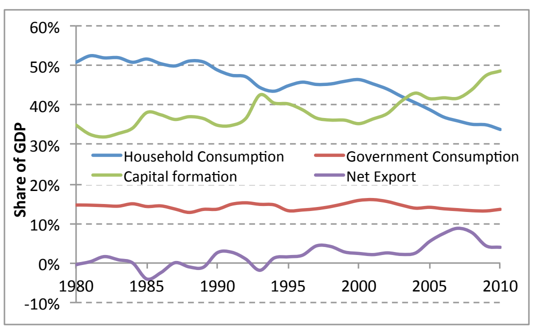


Figure 1.1: The Changing Trend of Share of GDP in China from 1980 to 2007 (NBS, 2011)

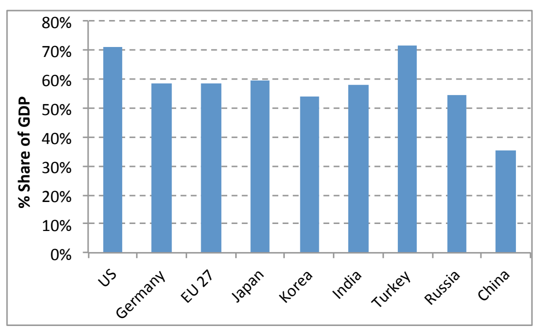


Figure 1.2: Share of Household Consumption in GDP of Different Countries in 2009 (OECD, 2013)

During the past three decades of rapid economic development, China's households have experienced huge lifestyle changes starting in near poverty conditions in the 1960s to fulfilling basic household needs and then toward pursuing higher living standards (Hubacek et al., 2011, 2007). Per capita annual disposable income for urban residents increased 660% from 2,514 Yuan in 1980 to 19,109 Yuan in 2010 (constant 2010 prices).

For rural residents, it rose 587% from 862 Yuan to 5,919 Yuan. With increased disposable income, per capita residential direct energy use rose 138% from 106.6 kg standard coal equivalents (SCE) in 1983 to 254.2 kg SCE in 2009. However, residential direct energy consumption has been growing more slowly than total energy use in China. As shown in Figure 1.3, the share of residential direct energy use decreased from 16.4% in 1980 to 10.7% in 2005. As a consequence of the low share of household consumption in GDP and the low share of residential direct energy use, most of China's energy conservation policies are focused on industries and largely neglect households.

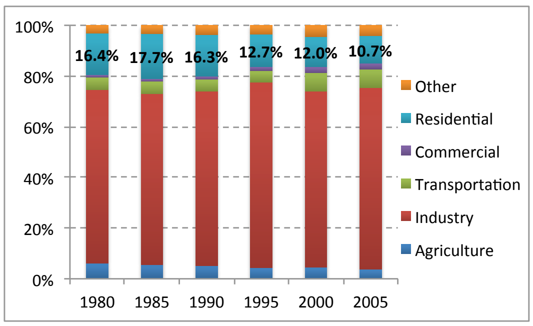


Figure 1.3: Share of Energy End Use by Sectors in China (NBS)

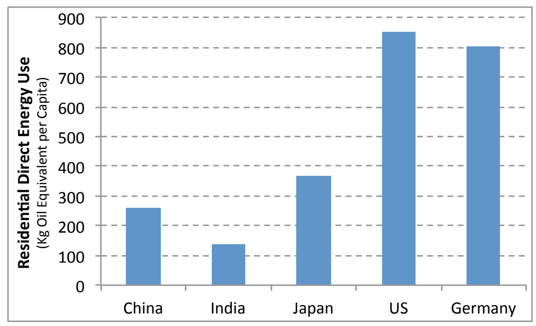


Figure 1.4: Per Capita Residential Direct Energy Use in 2009 (IEA, 2012)

The current export- and capital-investment-led economy is not sustainable. To balance its economic structure and to recover from its economic slow down, Beijing has tried to boost its domestic demand. The nation's ongoing urbanization and income-driven lifestyle change will cause energy consumption related to the household sector to rise significantly. As shown in *Figure* 1.4, residential direct energy use in China is 261 kg oil equivalent per capita, 71% of the Japanese level and only 30.6% of America's. It is natural to ask whether residential energy consumption growth in China will follow the Japanese model or the US model or perhaps some model different from these two. Considering its high population density, severe energy security issues, and environmental pressures, China needs to land on a more energy-saving model. Thus, guiding Chinese residents' lifestyles toward more sustainable ways of living will be a critical strategy for China's energy future.

This dissertation describes the changing household energy consumption patterns in

China during the past two decades. It also examines the socio-economic factors that influence these changes such as household wealth, urbanization, and lifestyle changes. As a spatially large developing country, China has significant regional differences not only in climate and geography, but also in economic development levels. This dissertation discusses changing patterns of residential energy use at the regional level, identifies the driving forces that have contributed to them, and details the contribution of interregional energy flows to each region. Beyond such macro-level analysis, this dissertation proposes a structure for analyzing residential energy consumption at the household level, one that incorporates both socio-economic factors and household characteristics. This dissertation proposes possible directions for reaching sustainable consumption in a rapidly changing, developing country like China.

This chapter is organized as follows. Section 1.2 presents the three main research objectives; Section 1.3 describes the research approach including classification of household energy consumption and study levels; Section 1.4 summarizes the thesis contributions, and Section 1.5 describes the thesis structure.

1.2 Objectives

This dissertation examines household energy consumption trends and explores main forces of changes with respect to household energy requirement in China. It aims to

1) Explore changes in household energy consumption patterns in China by considering both energy used directly in households' daily lives and which households used indirectly as embodied in goods and services they use.

2) Identify causes of changing patterns in household energy consumption by exploring how macro-economic changes (in technology, urbanization, and household lifestyles) have affected the energy embodied in household consumption.

3) Examine energy consumption patterns for urban households, rural households, and rural-to-urban migrants at the household level and explore factors that influence energy use for these three groups.

4) Suggest ways to better integrate household energy consumption into China's

energy conservation policies and find out how changes in China's economic structure might affect its household energy use.

1.3 Research Approach

Similar to the research framework of the "Lifestyle Research Project" in The Netherlands, this dissertation focuses on the relationship between changing lifestyle patterns and changing household energy requirements in China via changing household spending patterns (see *Figure* 1.5, Wilting and Biesiot (1998)).

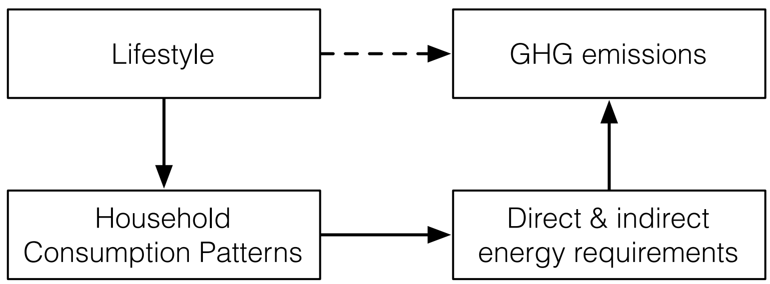


Figure 1.5: Research Framework of Relationships between Lifestyles and Corresponding Energy Requirements Via Household Consumption Patterns. (Based on Wilting and Biesiot, 1998, Page 66)

Household energy requirements contain household direct energy use and indirect energy use. Households use energy directly for heating, lighting, transportation, and other purposes. Households also use energy indirectly through purchased goods (*e.g.* food, cloth, etc.) and services (*e.g.* insurance, public transport, etc.). The energy used in the production and delivery of these goods and services is regarded as household indirect energy use (see *Figure* 1.6). Thus total household energy use in this dissertation refers to the sum of direct and indirect energy used by households.

In this dissertation, household energy requirements are expressed in terms of primary energy. Direct energy use contains in-home energy use and transportation energy use (see *Figure* 1.7). It is based on direct energy use data from the *Energy Statistical Yearbooks* of China. Also direct energy use in this dissertation refers only to household direct energy use of ***commercial energy***. Non-commercial energy sources such as firewood, straw, and biogas are also important energy sources for rural residents. In

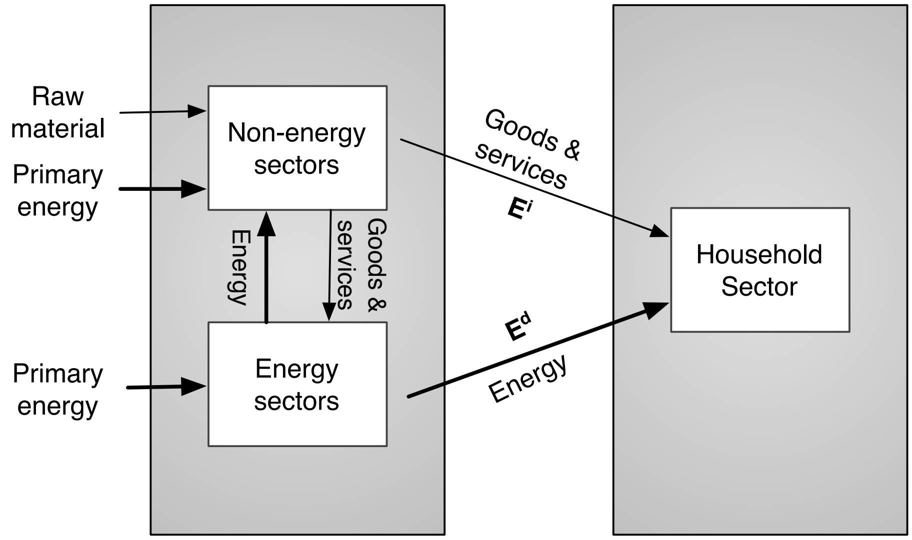


Figure 1.6: Direct (E^d) and Indirect (E^i) Energy Requirements of Households (Wilting and Biesiot, 1998, Page 65).

the following chapters, rural households' consumption of non-commercial energy will also be mentioned, although it is not explicitly included in the analysis and discussion sections. In the macro-level, indirect energy flows are calculated using a shift-share type analysis of energy usage for the production sectors and transactional flows of China's economy. For the household level, household indirect energy use is calculated based on the *consumer lifestyle approach* (Bin and Dowlatabadi, 2005; Feng et al., 2011; Wei et al., 2007).

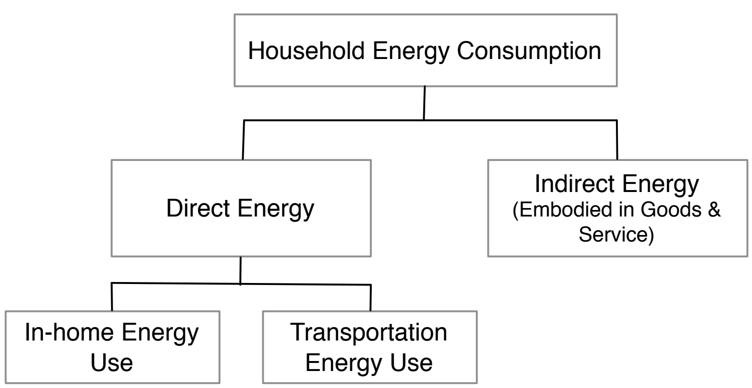


Figure 1.7: Components of Household Energy Consumption

This dissertation explores household energy consumption trends and identifies proximate driving forces of household energy requirement changes at both the national level and multiregional level. At the national level, China's national input-output tables are used to calculate indirect energy use for urban and rural households in 1987, 1992, 1997, 2002, and 2007. *Structural decomposition analysis* (SDA) is the technique used to investigate the key factors of changes in household indirect energy consumption from 1987 to 2007 in a shift share fashion. At the multi-regional level, China is divided into eight regions to observe the disparities of household energy use across regions. Multiregional input-output tables are used to calculate household indirect energy use for each region in 1997 and 2007. Again, SDA is used to diagnose the driving forces of changes in household indirect energy use by region from 1997 to 2007. Impacts of the interregional trade of goods and services to household indirect energy use in each region are also studied at the multiregional level.

At the micro-level, this dissertation contrasts the lifestyles of urban households, rural households, and rural-to-urban migrants in 2002. This household-level analysis is based on survey data from *Chinese Household Income Projects* in 2002. The *Consumer lifestyle approach* is used to link household expenditure patterns to household indirect energy use and related CO_2 emissions. Also, this dissertation explores how households choose to use energy based on their climate, socio-economic, demographic, and physical housing structures in China. In all three levels of analysis (national, regional, and household), household energy use and energy use patterns are displayed for urban and rural households separately to enable an understanding of how urbanization is likely to impact China's energy future.

1.4 Thesis Constributions

The dissertation provides a more detailed description and explanation of household energy consumption change in China from 1997 to 2007. The top-down national and multi-regional analysis and the bottom-up household level analysis enables triangulation to a fairly complete picture of past trends, spatial variations, and spatial spillovers of household energy consumption in China. This foundational analysis leads to some clear insight into viable possibilities for energy conservation policies in China.

This dissertation tells a story of how lifestyle change, particularly urbanization impacts household energy consumption. Compared to the snapshot view provided by most previous research, this study provides a longitudinal view of the effects of core factors that have induced changes in household energy use in China. Compared to treating the country as a united whole, the research presented here explores household energy requirements at a regional level. By doing so, it identifies severe issues with current policies and, thus, more viable directions for solving emerging problems. Methodologically, this study provides a new structural decomposition approach that can be used to analyze the residential sector. It distinguishes and diagnoses the effects of population change, changes in urbanization, per capita household consumption change, and changes in household consumption basket.

This dissertation compares lifestyles and the energy use of urban households, rural households, and rural-to-urban migrants. It includes climate and socio-demographic details in analyzing links between household consumption and indirect energy use. Also, it studies the energy use of rural-to-urban migrants, a large group of people in China who have been largely neglected by previous studies. Methodologically, this study applies the *consumer lifestyle approach* at the household level to quantify the impact of household lifestyles on indirect energy use and household related CO_2 emission.

1.5 Thesis Structure

The dissertation is organized as follows (see *Figure* 1.8):

Chapter 2 reviews theoretical literatures on household energy consumption from economic growth theories and sustainable consumption theories. It also discusses the recent empirical studies of household energy consumption from three aspects: key influencing factors, case studies in China, and international comparisons.

Chapter 3 describes changes in China's household energy use from 1987 to 2007 and explores the driving factors of changes in indirect energy use through structural decomposition analysis. This chapter also focuses on the impact of lifestyle changes on household energy use in four aspects: housing, ownership of home appliances, space heating and cooling and personal mobility.

Chapter 4 describes the regional disparities in household energy consumption from 1997 to 2007. It explores changes in direct energy use for each region through regional disparities in climate and thermal comfort, space heating and cooling demands, and electric home appliance usages. It also examines key factors for household indirect energy use through structural decomposition analysis and discusses the effect of interregional trade of final goods and services as well as changing trend of household consumption patterns at the regional level.

Chapter 5 implements the consumer lifestyle approach to quantify household indirect energy use. It compares the lifestyle and energy use disparities among urban households, rural households and rural-to-urban migrants. It also studies the impact of climate, income, household size and residential characteristics on household indirect energy use.

Chapter 6 summarizes findings from chapter 3 through 5, discusses their policy implications and suggests directions for future research.

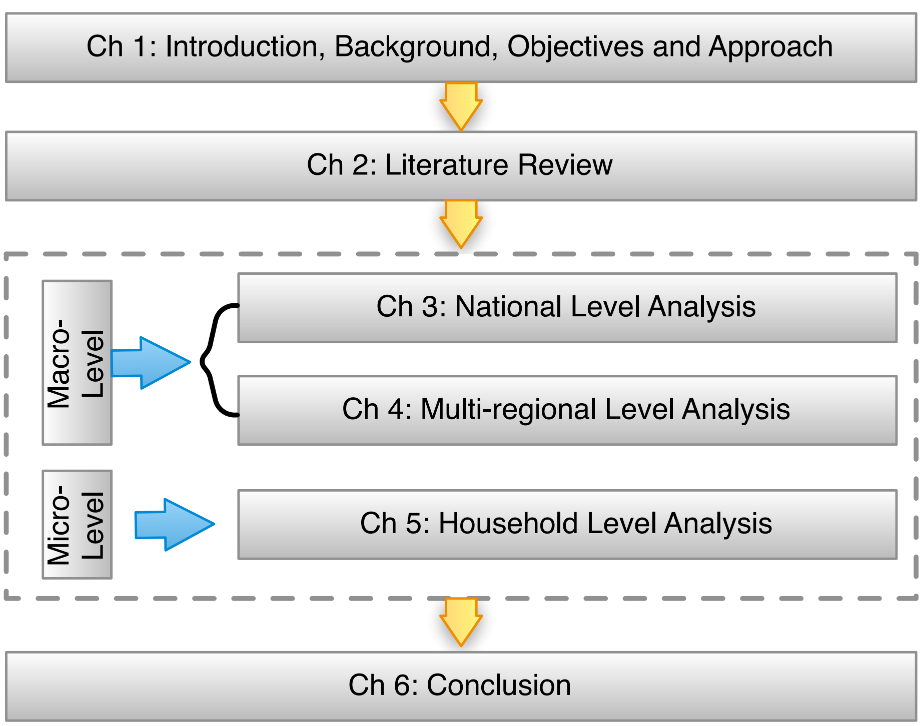


Figure 1.8: Dissertation Structure

Chapter 2

Literature Review

2.1 Introduction

This literature relevant to this dissertation looks at both the theories and empirical studies of household energy consumption. Neo-classical economic growth theory demonstrates that energy can drive economic development in many countries (Cleveland et al., 1984; Smil, 2005; Solow, 1999). A large body of empirical tests of the theory confirms it (De Almeida et al., 2011; Park and Heo, 2007; Peters et al., 2007; Vringer and Blok, 2000). As China gradually turns into a consumer society, household energy consumption has tightened its relationship with economic development. Since energy use typically results in air pollution, it is often used as an indicator of environmental degradation. Interestingly, however household energy consumption did not follow the trend of Environmental Kuznets Curve that it predicts a decrease as income rises. This is because household energy requirements in both developed and developing countries increase even under a regime of significant energy efficiency improvement in producing sectors. Rebound effects partly explain why the more efficient use of energy actually increases total energy consumption. But it fails to capture the effect of shifting consumer demand. Households have an enormous influence on the direct use of energy as well as through indirect use as embodied in goods and services. Sustainable household consumption is widely used in research and practices to demonstrate the obligations that households should fulfill.

Empirical studies indicate that household energy consumption has been increasing in both developed and developing countries. In developed countries, the rise in information technologies and entertainment use has been a prime factor. For developing countries, a prime motivator had been improving living standards. Previous studies also center on factors of both supply and demand side that may affect household energy requirements. In the supply side view, a change in energy consumption is often decomposed into changes in energy efficiency, production input structure, consumption structure, and consumption levels. Household level analysis studies the effect of climate, socio-economic, social demographic, social cultural and behavioral factors. Climate factors and socio-economic factors significantly affect households' energy consumption. The effect of demographical change (such as aging), cultural difference, and behavioral models are also examined in some empirical analysis.

2.2 Economic Growth Theory

The role of energy in economic growth has been a controversial topic in previous studies. Traditional growth models treat energy as an intermediate factor that has little affect on economic growth. Some more recent entries to neoclassical growth theory include energy as an important input beside labor and capital for production (Cleveland et al., 1984; Solow, 1999). With technological improvement, cheaper and more convenient energy has encouraged the substitution of energy derived mechanical power for work done by animals and humans.

As a key driver of economic growth, energy security and availability have always been hot topics on the political agenda around the world. Unfortunately, as a modern necessity, energy also is a main contributor to local air pollution and global climate change. To respond to energy security and environmental pollution pressures, energy policies have focused on the supply-side issues such as economic structural change, technological improvement, and regulatory management (Casler, 2001; Garbaccio et al., 1999; Howarth et al., 1993; Metcalf, 2008). Lately, demand-side policies have been gaining more attention from researchers and policy makers. The Johannesburg Plan of Implementation encouraged "*fundamental changes in the way societies produce and consume are indispensable for achieving global sustainable development* (United Nations, 2004). Sustainable consumption also is gaining momentum within the public debate.

2.2.1 Environmental Kuznets Curve

Kuznets (1955) proposed an inverted-U curve relationship between economic development and income inequality. The theory known as the *Environmental Kuznets Curve* (EKC) suggests that pollution first increases with income, then decreases. At low levels of development, the intensity of environmental degradation is low due to limited economic activity. But during early stages of growth, energy degradation gets worse. The resource depletion rate exceeds resource generation rates. Pollution begins to accumulate at toxic levels. After some turning point, the use of natural resource and pollution emissions start to decrease with income. At higher levels of economic development, a reversal of the trend is caused by 1) the structural changes from production modes that support environmental degradation and consumption shifts toward less-resource-intensive service industries; 2) increased environmental awareness; 3) higher governmental expenditures on environmental monitoring and control as well as stricter environmental regulation (Stern, 2004; Stern and Common, 2001; Stern et al., 1996).

As a main contributor to air pollution, energy is a viable indicator of environmental degradation. Energy use is often used to test the EKC assumption. Smil (2005) indicates that "*energy intensities rise during the early stages of industrialization, peak and then decline as economies use energy more efficiently*". However, empirical studies show that, unlike intensity, household energy consumption in both developed countries and developing countries does not fit into EKC.

Electricity consumption by European Union households increased by 2% per year over the past ten years despite significant energy efficiency gains in household appliances and lighting (De Almeida et al., 2011). Total household energy requirements per capita in the Netherlands grew an average of 2.4% per year from 1948 to 1996. During the same time period, total energy intensity per household had increased at just 0.25% per year (Vringer and Blok, 2000). Household energy requirements grew even faster in transition countries. In Korea, direct household energy demand increased at an average annual rate of 8.4% in the 1980s and 7.2% in the 1990s, even under progressive electricity tariffs for households (Park and Heo, 2007). Peters et al. (2007) found that final demand growth, which is driven by urbanization and lifestyle changes, led to growth in CO_2 emission for China from 1992 to 2002 while technology and efficiency improvements have only partially offset the impact of consumption growth. Energy efficiency improvements in production processes and end uses could not offset the rapidly increasing demand in both developing and developed countries.

2.2.2 Rebound Effects

Rebound effects partly explain why more efficient use of energy will actually increase total energy consumption (Ayres and van den Bergh, 2005; Greening et al., 2000; Madlener and Alcott, 2009). With the existence of a rebound effect, energy efficiency policies may serve the goals of promoting economic growth. However, energy efficiency improvement may actually lead to more resource use in absolute terms.

Rebound effects are composed of four types. The first level is a *price effect*. For producers, increased productivity reduces production costs and theoretically enables an increase in supply. The second level is an *income effect*. When costs per unit of output fall, consumers can afford more energy-intensive products and services. Wilhite (2007) points out that the introduction of new technologies may at the same time create new energy-intensive practices. The third is a *substitution effect*. As the share of energy use in total expenditures reduces, the demand for other goods and services rises, including goods and services that have large share of energy embodied in their production. The increased demand for new goods and services requires more energy. The last level is a *transformation effect*. Fuel efficiency and other technological improvements alter human activity through changes in the allocation of time (Greening et al., 2000).

Empirical work testing the rebound effect theory fails to recognize two points. First, most of the studies only focus upon technical change that affects energy efficiency. The effect of shifting consumer demand to higher living quality is missing. Understanding such shifts in consumer demand is very important, especially for developing countries like China. Second, few empirical studies consider the transformation effect (Madlener and Alcott, 2009). The substitution of energy for time via the use of time-saving electric appliances or transportation modes is rarely considered.

2.3 Sustainable Consumption

In 1994, the Oslo Symposium on Sustainable Consumption defined **Sustainable Consumption** as "*the use of goods and services that respond to basic needs and bring a better quality of life, while minimizing the use of natural resources, toxic materials and emissions of waste and pollutants over the life-cycle, so as not to jeopardize the needs of future generations*" (Norwegian Ministry of the Environment, 1994). Since then, this definition has been widely used in the research and practices of sustainable consumption. *Sustainable Consumption* is a site- and problem-specific concept. Also, it is a dynamic concept that indicates only the direction of desired or required changes (OECD, 2002b). In general, sustainable consumption is a long-term process involving negotiation and consensus building.

2.3.1 Consumer Decision-Making

Understanding the decision making process of consumers is the key to the study of what might constitute sustainable consumption. Consumer decision-making is a complex process affected by different and sometimes competing criteria, including self-interest motives (*e.g.,* price, income, quality, personal taste, and lifestyle) and social and economic motives (*e.g.,* culture, self-identity, and environmental and social concerns) (Moisander, 2007). The *Economic conceptual framework* is rooted in consumer preference formation and studies how the consumption of different goods and services interact with each other within aggregate consumption (OECD, 2002b). On the other hand, the *systems of provision model of consumption* views consumption as an active social process rather than just the sum of individual behaviors (Chappells et al., 2000). Consumption processes are connected to production and distribution systems (*e.g.* technological and infrastructure networks) that enable certain lifestyles.

Needs–Opportunities–Ability (NOA) model is the basic model used to diagnose specific forces underlying consumer behavior at both the macro-level and micro-level (Gatersleben and Vlek, 1998) (See *Figure* 2.1). Based on the Motivations-Opportunities-Abilities model, consumer behavior is determined by the needs, opportunities, and abilities of people to fulfill their own needs (Ölander and Thøgersen, 1995; Robben and Poiesz, 1993). *Needs* refer to a series of objectives that individuals pursue to maintain or improve their "quality of life." Households need energy to provide a range of "services," such as to heat and cool rooms and to run home appliances. Households' energy needs grow along with increasing demand for higher comfort levels such as larger houses, more comfortable indoor temperatures and higher hygiene needs. *Opportunities* are a set of external facilitating conditions, such as availability and accessibility of goods, services and relevant information. *Abilities* are the set of households' internal capacities to pursue goods and services. They include financial (*e.g.* income), temporal (*e.g.* leisure time), spatial (*e.g.* home vacant space and location of house), cognitive and physical (*e.g.* health, fitness), and skill (*e.g.* possess of licenses and permits) abilities (Gatersleben and Vlek, 1998). Opportunities and abilities determine a consumer's level of behavioral control.

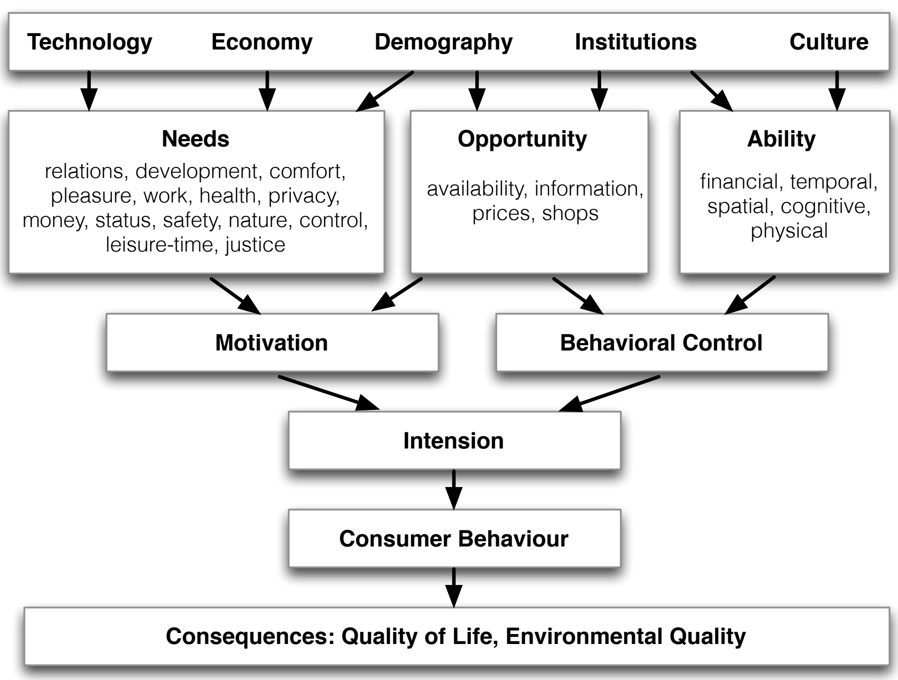


Figure 2.1: The Needs–Opportunity–Ability Model of Consumer Behaviour (Gatersleben and Vlek, 1998)

Jackson (2005) describes sustainable behavior as "*a function of partly attitudes and intention, partly of habitual responses, and partly of the situational constraints and* *conditions under which people operate.*" The NOA model is embedded in five social contexts: *technology*, *economy*, *demography*, *institutions*, and *culture*. Technology improvement and economic development increase consumers' purchase *opportunities* and *abilities* through mass production and lower prices. Demographic changes yield a multiplier effect on consumption as population increases. Institutions, especially government, might constrain consumers' *opportunities* and *abilities* by prices or regulations. Cultural norms and values might also penetrate into the consumption process through influencing consumers' *needs* and *opportunities*. For example, consumers' sense of "quality of life" and their household energy consumption behavior depend highly on their cultural habits and routines (Brohmann et al., 2009). The NOA model provides a useful structure for analyzing the driving forces of household energy consumption change at both the macro- and micro-level. Also, It provides a dynamic framework of consumers' behavior through consumer's ability and willingness to change.

2.3.2 Sustainable Consumption Policies

The production and consumption of key consumer goods and services, especially fuel, induces negative environmental externalities. These externalities arise from improperly defined rights, market failures, and government failures (OECD, 2002b). Based on the exsistence of environmental externalities, the OECD (2002a) proposes a framework to promote sustainable household consumption (see *Figure* 2.2). In this framework, achieving sustainable consumption requires a multi-stakeholder approach the includes efforts of government, the market, NGOs, and individual consumers.

As a traditional regulator, government could play a central and active role in steering consumption towards more sustainable patterns via market-based instruments and regulatory instruments. Consumers also have a central role in shaping the pattern of consumption. For example, consumers' demand for environmentally sustainable products can stimulate the supply of such products. Since consumers are heterogeneous, civil society groups such as NGOs and public participation groups are very important in facilitating the sustainable consumption process. They play an important role as information regulators for both production and consumption sides. They are also likely

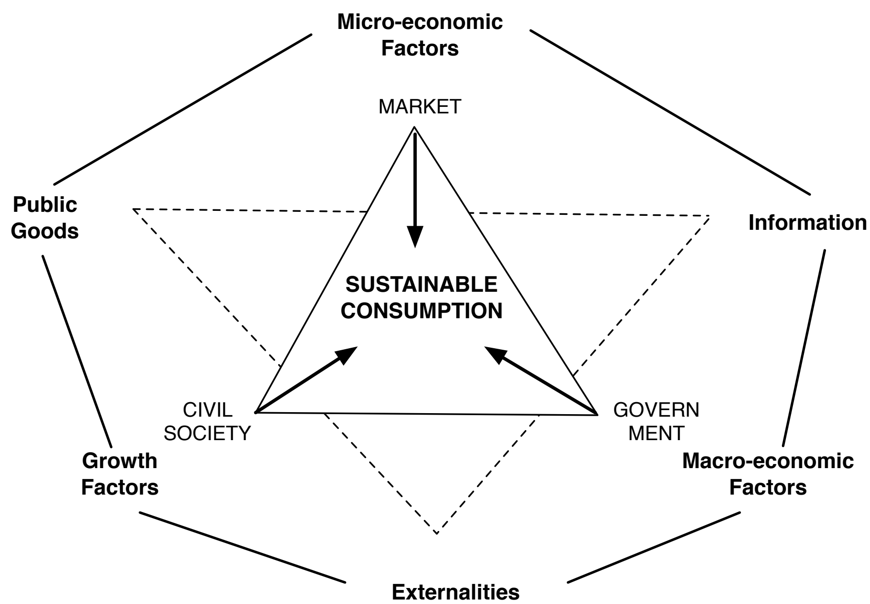


Figure 2.2: OECD's Conceptual Framework of Sustainable Consumption (OECD, 2002a)

to stimulate governments, corporations, and households to change their behavior in order to protect environment.

Sustainable consumption policies primarily focus on steering overall individual consumption patterns towards more sustainable ways. Individual consumers can reduce their environmental footprints by using fewer non-renewable energy (*e.g.* coal and oil) and energy-intensive commodities and more eco-efficient renewable energy (*e.g.* solar power) and eco-efficient products and services (*e.g.* public transport) to achieve a similar comfort level (OECD, 2002b). However, households' abilities and willingnesses to choose these options also largely depend on other conditions outside of their control, such as the availability of goods, services, information, and environmental regulations or legislation (OECD, 2002b).

Three types of policy instruments are often used to influence consumer decision-making. *Economic instruments* are mainly price-based since the prices of energy, products and services may not fully reflect their full social costs. However, they may be less effective when price is not a key decision criterion for consumers. Also, they may raise social equity concerns. In OECD countries, economic instruments include full-cost pricing, environmental taxes and charges, green tax reforms, and the removal of environmental harmful subsidies (OECD, 2002b). *Regulatory instruments* influence household consumption pattern through imposing or improving standards or requirements mainly on the production side. Minimum energy efficiency standards, building regulations and energy-efficient labeling requirements are widely used regulatory instruments in OECD countries (OECD, 2002b). Most of these regulations are targeted to the producers, direct regulations on consumers are relatively rare because they are more costly, intrusive and difficult to enforce. *Social instruments* are mainly information-based and are often used to influence consumers' knowledge and willingness to act in favor of environment (OECD, 2001). Eco-labeling, public awareness campaigns, open forum debates, and voluntary coordinated consumer initiatives are used to make consumers aware of how they could approach a more sustainable lifestyle (OECD, 2002b).

2.4 Influential Factors on Household Energy Consumption

Research on household energy consumption not only focuses on energy directly consumed by households (direct household energy requirements) but also energy embodied in the goods and services consumed by households (indirect household energy requirement). Reinders et al. (2003) evaluate the average household energy requirements of eleven European Union countries. The share of direct energy use of the total energy requirement varies from 34% to 64% in these countries. Variations mainly depend on differences in total household expenditures. Greening et al. (2001) compare the effects of changes in residential end-use and behaviors in ten OECD countries and find that changing trends of final residential energy consumption vary widely by country. The following subsection discusses the current research that explores key drivers of household energy consumption from three perspectives: factors from the production-side view, factors from the household-side view, and methods used to explore these factors.

2.4.1 Production-Side View

Decomposition analysis is commonly used to understand the changing trends of energy consumption due to a set of key comparable economic forces. Changes in energy consumption are usually classified into two categories: efficiency improvements and structural change (Garbaccio et al., 1999; Metcalf, 2008). Efficiency improvements reduce energy use to produce a product within a particular sector while structural change is an alternative in the share of economic activities among sectors (*e.g.*, shifting from energy-intensive activities to less energy-intensive activities). Howarth et al. (1993) find that structural change caused nearly all the decline in energy intensity in Norway and about half of the decline in Japan from 1973 to 1988.

Early discussions of post-1978 changes in China's energy intensity tended to attribute most of the decline to structural change. Lin and Polenske (1995) used structural decomposition analysis to examine China's energy use from 1981 and 1987 and found that technical change nearly accounted for all of the energy intensity reduction while structural change was actually responsible for a slight increase in energy intensity. Garbaccio et al. (1999) extended the research boundary to 1987 and 1992 and obtained similar results. Sinton and Levine (1994) declared that energy efficiency improvements accounted for most of the drop in industrial energy intensity in the 1980s. However, Huang (1993) supported that efficiency improvements were a main contributor to aggregate energy intensity reductions but found further that structural change contributed little to energy intensity change. Zhang (2003) discovered that the energy efficiency improvements of the 1980s were maintained into the 1990s. That is, from 1990 to 1997, 88% of energy savings by the industrial sectors could be attributed to energy efficiency improvements. Looking at firm-level data, Fisher-Vanden et al. (2006) saw that nearly half of the change in energy intensity had been gain in energy efficiency at the firm level from 1990 to 1997. Studying structural change at different levels of aggregation may also yield different results.

The trend of decreasing energy intensity since the 1980s reversed since 2001. Energy consumption grew 1.2-1.4 times more rapidly than did GDP from 2001 to 2005. Ma and

Stern (2008) indicated that the rise in energy intensity since 2000 was partly caused by "negative technological progress." That is, technology put in place appeared to work against improvements in energy efficiency. Xia et al. (2012) found that although changes in energy efficiency caused energy intensity to rise, the effect was small and that final demand and changes in its structure explained much of the energy intensity increase from 2002 to 2005. Kahrl and Roland-Holst (2008) identified that exports had become the largest source of energy demand growth in China since China's access to the World Trade Organization in 2001.

2.4.2 Household-Side Analysis: Micro-level

Income is well-known to have a significant and positive effect on household energy consumption. Income affects household energy use behavior in several ways. On one hand, it influences the level of consumption via income elasticity parameters. That is, rising income leads to an increasing demand for more electronic appliances and larger houses. In the case of appliances, demand for time-saving devices rises with increases in opportunity costs for time, which require households to use and purchase more energy. Much research supports this hypothesis (Cayla et al., 2011; Lenzen et al., 2006; Vringer and Blok, 1995). The average household energy requirement is 173.6 GJ in Brazil, with 32.8 GJ for the low-income households and 602.2 GJ for the high-income households (Cohen et al., 2005). Moll et al. (2005) compared the average household energy requirements for different income groups of households in Netherlands, the United Kingdom, Norway, and Sweden and found that different levels of income yield different energy consumption behaviors. Low-income households use greater shares of their household budget for heating and electricity and lower shares for motor fuel, transportation and recreation.

On the other hand, income also affects the diffusion of energy-efficient equipment. Higher income gives consumers the ability to invest in energy-efficient appliances and other rather expensive energy conservation techniques such as better insulation and double-glazed windows. Richer households tend to replace older and less efficient appliances more frequently (Brohmann et al., 2009; Cayla et al., 2011). Also, higher income is often linked to higher levels of education, and thus to greater environmental information access as well as greater environmental awareness. All of these factors are important in energy conservation. However, Cayla et al. (2011) indicate that rich households may lack interest in energy-efficient equipment when the budget share dedicated to such an item is small.

Home ownership also plays an important role in household energy use, especially in rented dwellings. Households in rented dwellings tend to consume more energy if heating costs are included in the rental rate (Leth-Petersen and Togeby, 2001). Home ownership is often related with specific durable products and services as well, which also can influence household demand for energy services. In China, renters use less electricity than homeowners merely because they own fewer electric appliances such as refrigerators, washing machines, and air conditioners (Zhang, 2010). Also, the mobility of a household, which is associated with homeownership, can influence households' ability and willingness to invest in energy-efficient appliances and sustainable building design (OECD, 2002b).

Energy consumption behaviors that contribute to increasing energy demand are different in developing versus developed countries. In Mexico, cooking, water heating, lighting, and electrical appliances are the fast-growing end uses (Rosas-Flores and Gálvez, 2010). In Vietnam, a large share of energy used by rural and newly urbanized household is dedicated to cooking (Tuan and Lefevre, 1996). In China, water heating and space heating dominate the set of fast-growing energy end uses among households (Zhou et al., 2009). In OECD countries, rises in household direct energy use form 1970s to 2000 were attributed to electric home appliances and an ever-increasing demand for indoor air-temperature comfort (OECD, 2002b). A typical individual's consumption choice in modern society no longer has much to do with basic biological needs like food or shelter (OECD, 2002a). Individuals' choices with respect to the amount and quantity of recreation, amusement, housing, food and other consumables are linked to past or familiar experience, cultural norms, peer influences, and other social influences like those from the media. Information technologies and entertainment loads are key contributors to electricity demand (De Almeida et al., 2011). Compared to developed countries with similar climates, the households' demand shares for energy via space heating and cooling are rather low in Shanghai. Chinese households tend to sacrifice indoor thermal comfort to maintain spending levels on other household items like entertainment and information technology that are apparently deemed more essential to maintain a present-day Chinese lifestyle (Chen et al., 2009).

2.4.3 Household-Side Analysis: Macro-Level

Many macro-level factors such as climate, technology, infrastructure, energy price, and existing policies play an important role in influencing household energy consumption.

Of these, household energy consumption probably varies most with local **climate** conditions. Places with moderate temperatures such as coastal California, have much lower energy consumption levels than do places with temperature extremes like Texas. A typical household's carbon emission is 78% higher in Memphis than in San Diego (Glaeser and Kahn, 2010). Zhang (2004) finds that household energy consumption is strongly related to heating degree days (HDD) in China, Japan, USA and Canada.

Energy prices also influence household energy consumption. They are positively correlated with sustainable energy use: higher energy prices result in reductions in energy use. Brohmann et al. (2009) suggest that higher energy prices cause households to be more responsive in terms of their energy use. But generally household energy demand is perceived to be relatively price inelastic since it has become a modern-day necessity. In Germany, the price elasticity of energy demand generally ranged from -0.2 to -0.1, indicating higher energy prices might only cause a moderate reduction in energy demand, a 1% rise in energy price causes a 0.2% to 0.1% drop in energy demand (OECD, 2002b). Also, the price elasticity of energy demand is asymmetric. Consumers seem to be more sensitive to energy price rises than to energy price declines. In OECD countries, energy intensity fell rapidly following the rises in oil price in 1973-1974 and again 1979. But there was no apparent share rise in energy use after 1985 when energy prices fell back nearly to their pre-shock levels (OECD, 2002b). The asymmetry is probably due to medium- to long-run adjustments to the higher energy prices by making capital investments that induce more-efficient energy use as well as to expectations of future prices rises. Using firm-level panel data from 1997 to 1997, Fisher-Vanden et al. found that rising relative energy prices is an principal driver of China's declining energy intensity. Hang and Tu (2007) reviewed energy price deregulation process in China between 1985 and 2004 and found that higher relative price of different energy types led to decrease in coal and oil intensity. However, the positive electricity elasticity after 1995 indicated that price effect was weaker than income effect and population effect.

Energy efficiency improvements can be "locked in" to economies through changes in **technology** and **infrastructure** – the capital investments identified in the preceding paragraph. Infrastructure such as housing stock and public transport are parts of the "hardware" that shape household consumption pattern. Household energy use is strongly influenced by dwelling type and age, surrounding structures, and other housing characteristics such as insulation and building regulation (Steg, 2008). Increased boiler efficiency, double-glazed windows, better insulation, and more energy efficient home appliances all contribute to household energy conservation. Through such technological innovations, energy consumption in houses built in the Netherlands after 2000 is only 40% of that of homes built in the 1960s (OECD, 2002b). Interestingly the technological innovations are not always costly. The OECD (2002b) indicates that at least 20% of energy used for space heating could be saved at relatively low cost in existing housing stock.

Demographic factors also substantially affect household energy consumption through ownership and choice of appliances and household behavior. Several studies explore the influence of key demographic factors such as *population size*, *age structure*, *household size* and *urbanization*. O'Neill and Chen (2002) found that some demographic factors, particularly household size had substantial influence in residential energy use. Households with fewer members tend to use more energy per capita than do larger households. Shifting from a one-person to a two- or more- person household yields reductions on the order of 20% in household direct energy use per capita in OECD countries (OECD, 2002b). Aging also influences residential energy consumption since energy consumption tends to change over one's lifespan. Elderly households tend to be more energy intensive than are other households. Hamza and Gilroy (2011) also suggest that decisions made by an aging population could disable the ability of the British government to meet its energy-saving targets.

Urbanization is associated with both higher income and higher household energy use. There are big disparities in household energy use between urban and rural people in developing countries. Since people in urban areas are more likely to have access to commercial fuel supplies and the electricity grid, urban homes use more commercial fuels (Dzioubinski and Chipman, 1999). Increasing urbanization levels will lead to increased adoption of electronic home appliances, lighting, and other "amenities." Urban residents' lifestyle change further contributes to the trend of energy consumption growth. In developed countries, households in high-density areas are less energy intensive. Norman et al. (2006) conducted an lifecycle analysis on two residential settlements with different density levels in Toronto, and found that residents in high-density areas consumed less than half of operational energy and produced half the greenhouse gas emission compared to their counterparts who live in low-density areas. According to Ewing and Rong (2008), households in sprawling regions are more likely to live in large, detached single-family houses, which consume more operational energy than do single-family houses in compact regions.

Cultural and traditional attitudes toward certain goods and behaviors can influence preferences and behaviors that drive household consumption patterns. Culture and traditions are typically passed from generation to generation and are largely bestowed upon an individual over his or her lifetime. Abrahamse and Steg (2009) and Vringer et al. (2007) suggest that socio-demographic factors such as income and household size shape households opportunities and basic needs for energy, while reductions in energy use requires a conscious effort – a change in households' behaviors. Wilhite et al. (1996) compared energy use behaviors in Japan and Norway and found very different space heating, lighting and hot water use between the two countries. Not surprisingly, higher hot water usage in Japan was caused by the bathing habit in Japan (both publicly and privately), which had deep cultural roots. Also Norwegians tended to be more energy insensitive when it came to lighting and heating, as they have less annual sunlight and colder average annual temperature. Perhaps more surprisingly, however is that Norwegians heated much of their living areas most of the time, while Japanese tended to heat only rooms they were immediately using. Low energy prices in Norway may explain some of this discrepancy in behavior. But Wilhite et al. (1996) suggested that Norwegians also may have a cultural, physical, and psychological affinity for having all rooms heated.

2.4.4 Method

Input-output analysis is frequently used to calculate total energy requirements of households (Lenzen et al., 2006; Munksgaard et al., 2000; Nansai et al., 2008; Pachauri and Jiang, 2008; Pachauri and Spreng, 2002; Park and Heo, 2007; Vringer and Blok, 1995; Wier et al., 2001). Kok et al. (2006) summarized three types of I-O analysis used by researchers. First is basic I-O energy analysis. This method is based on data for the production side of the economy. This method is useful for describing environmental impacts of a specific country or comparing differences among countries. The second method combines I-O energy analysis with household survey data. In this method, the consumption data is from household expenditure surveys rather than I-O tables. It combines energy intensities of different economic sectors or commodities with household expenditure survey data. This method can generate more information on the household level and compare the energy requirement of different household types. The third method combines life-cycle analysis with I-O analysis. It leads more detailed information on both production and consumption side. It is good at describing and explaining environmental impacts at the household level.

Based on basic I-O method, Liu et al. (2011) calculate CO_2 emission from China's household consumption from 1992 to 2007 and find that the household sector accounted for over 40% of total CO_2 emissions that generated through primary energy utilization. Logarithmic Mean Divisia Decomposition analysis indicates that rising total population, urbanization and household consumption per capita all contribute to the growth of indirect CO_2 emissions from 1992 to 2007 while reduced carbon intensity mitigated the growth of carbon emissions (Liu et al., 2011). Fan et al. (2012) explore how the embedded carbon footprint of Chinese urban households evolve with rising income activities from 2003 to 2007. When per capita household expenditure exceeds 10,000 Yuan (constant 2005 prices), household CO_2 emission intensity actually increases with the consumption level. Liu et al. (2009) quantify household indirect energy use in China from 1992 to 2005. Based on the 2005 I-O table, Liu et al. (2009) use an adjusted input-output price model to test how alternative energy policies such as energy efficiency improvement and rising electricity prices will impact production prices, consumption prices and household real income.

Bin and Dowlatabadi (2005) propose a *Consumer Lifestyle Approach* (CLA) as an alternative paradigm to explore the relationship between household consumption activities and their environmental impact. In CLA, the consumer's decision making is affected by five major interacting groups of factors: 1) external environmental factors (*e.g.* traditions and technology levels); 2) individual determinants (*e.g.* attitudes and personal preferences); household characteristics (*e.g.* housing size, household types and size, and household income); 4) consumer choices (*e.g.* information and availability of goods and services); 4) consequences (*e.g.* consumption related material, energy use, and environmental impacts) (Bin and Dowlatabadi, 2005).

Based on CLA, Wei et al. (2007) quantify the direct and indirect energy use and related CO_2 emissions of Chinese household from 1999 to 2002. Household consumption accounts for about 26% of total primary energy use and about 30% of total CO_2 emission in China. Based on Wei et al.'s study, Feng et al. (2011) compare household energy use and CO_2 emission for different income groups and of different regions. Feng et al. (2011) find that income has a significant effect on the amount and structure of household indirect energy use in China. High-income households tend to consume more energy indirectly through goods and services and have more diversified indirect energy consumption structure.

Micro-level survey data is also widely used in determining household energy requirements (Cayla et al., 2011; Narasimha Rao and Reddy, 2007; Pachauri, 2004). Combining India's national household expenditure survey data with estimated energy intensities of production sectors, Pachauri (2004) quantifies household direct and indirect energy requirements at the household level in 1993. Pachauri (2004) also explores the key influential factors of household energy requirements through multi-variable regression. Based on the same dataset for the year 1999, Narasimha Rao and Reddy (2007) use a Multinomial Logit model to analyze key factors that affect households' energy choices for cooking and lighting in India. O'Neill and Chen (2002) employed *Residential Energy Consumption Survey* and *Residential Transportation Energy Consumption Survey* data to test the effects of demographical determinants of household energy use in the US. O'Neill and Chen's study reveals that some demographical factors, particularly household size, have substantial influence on household energy use.

Most micro-level studies of household energy use are at the city or county level (Jingchao and Kotani, 2012; Niu et al., 2012; Tonooka et al., 2006; Wang et al., 1999; Ye et al., 2011). At the national level, Golley and Meng (2012) used China's Urban Household Income and Expenditure Survey data to explore the effect of income on household carbon footprint. Since China does not have national surveys that collect energy-related data for households, most research of household energy consumption in China is at the macro-level (Chen et al., 2008). Thus there appears to be room for micro-level studies that could contribute to a more complete understanding of key factors behind various household energy consumption patterns.

2.5 Case Studies of Household Energy Use in China

Household energy consumption has been increasing in both rural and urban China. In rural China, per household direct energy consumption was only 0.46 to 0.54 kg SCE per day in the 1960s and 1970s. Household energy consumption barely met human basic needs such as cooking. Starting in the 1980s, the cooking fuel shortage was gradually solved via this period's rapid development of agriculture, which enabled the availability of more straw and other grain stalks. At the same time, rural households started to use more commercial energy as coal, gas, and electricity became increasingly available in the rural market place (Wang and Feng, 2001). Urban households went through a similar transition, from an energy shortage to enough energy to meet basic needs and then further to a demand over basic requirements. Compared to their rural counterparts, urban households devote much larger shares of their consumption baskets to commercial energy (Pachauri and Jiang, 2008).

During the process of energy commercialization, fuel mixes in both urban and rural households changed dramatically. In urban China, the share of electricity and LPG increased significantly from 10% to 42% between 1990 and 2000 while the share of coal decreased from 85% to 43% (Liu et al., 2005). In rural China, annual per capita energy consumption increased about four fold from 389 kg SCE in 1979 to1314 kg SCE in 2007. The share of biomass decreased dramatically from 71% to 31% (Zhang et al., 2009). A case study of rural development in Yangzhou County indicated that the share of LPG and electricity increased from 0.9% and 12.1% to 11.3% and 18.8% from 1992 to 1996 while the share of straw decreased from 62.6% to 47.1% (Wang et al., 1999). The fuel mix transition from biomass and coal to cleaner and more efficient fossil-based energy sources significantly improved both local and indoor environments. The transition of fuel composition could be partly explained by households' intensifying share of direct energy use among all household purchases. In urban China, the share of delivered energy used for cooking and heating decreased from 88% to 76% from 1991 to 1995, while the share of energy used for lighting, cooling, and electric appliances increased from 12% to 24%. Since the 1980s, the main fuel for cooking and hot water has gradually switched from coal to gas in urban China (Liu et al., 2005).

Many studies indicate that household direct energy consumption also varies tremendously across China. Per household CO_2 emissions in Northeastern China are 69% higher than the national average level. However, in cities of Western China, per capita household CO_2 emission is 17% lower than the national average (Zheng et al., 2010). Rural households in Northeast, South, and Southwest China tend to be more likely to use biomass than are other regions (Zhang et al., 2009). Also, end use of household energy varies substantially across regions. A typical urban household in Guangzhou uses 25% of household energy for cooking, 24% for cooling, 24% for electric appliances, 9% for bathing and 8% for lighting, while a typical household in Beijing uses 68% of energy for heating, 11% for heating, 11% for electric appliances, and only 1% for cooling (Liu et al., 2005).

Lifestyles have an important effect on energy use and CO_2 consumption. In China, per capita residential energy consumption has increased nearly 50% from 1990 to 2007. Households tend to consume larger amounts of indirect energy through the use of household goods and personal services than through their direct consumption of energy (Liu et al., 2009). And here too, big disparities exist between urban and rural residents. For urban residents, indirect energy consumption is 2.4 times greater than the direct energy consumption while for rural residents, direct energy consumption is 1.9 times higher than indirect energy consumption in 2000 (Wei et al., 2007). Feng et al. (2011) find that direct energy consumption per household increased faster in urban areas than in rural areas from 2005 to 2007. The structures of indirect energy consumption and CO_2 emissions are more diverse for urban households than for their rural counterparts. Changing lifestyles will significantly increase total energy consumption in China.

China issued its first *Energy Conservation Law* in 1997 and then amended it in 2007. The amended version aims to "*promote energy conservation in the whole society.*" Energy efficiency improvement are an explicit and critical component of China's energy policy. In the Twelfth Five Year Plan (FYP), China committed to cutting by 16% the 2010 level of energy use per unit of gross domestic product (GDP) by 2015 (National Development and Reform Commission, 2011).

Residential energy consumption policies focus on improving the efficiency of residences and home appliances. In 1986, China enacted its first residential building energy efficiency code in the severe cold and cold regions (JGJ 26-86). In 2003, the enactment of an energy efficiency code for hot summer and warm winter zones (JGJ 75-03) indicated that all regions in China have their own building codes. Besides that, northern China retrofitted existing heating systems and installed heating meters to enhance the efficiency of both energy delivery and energy consumption. In the 11^{th} FYP (2005-2010), the Chinese government set up an ambitious energy conservation target for new buildings. It requires new buildings to be 50% more energy conservative than the current building standard. Major cities such as Beijing and Tianjin should implement a stricter 65% energy-saving standard (Shui et al., 2009). Although the use of home appliances quickly saturated households during the past 30 years, they remained relatively energy inefficient compared to those used in developed countries. To improve energy efficiency, voluntary energy-efficiency labeling began in 1998. In 1999, China instituted a mandatory minimum efficiency standard. In 2005, it launched a public energy information campaign. Moreover, China has slowly tightened its energy-efficiency standards over time.

Although China had already developed a legal foundation in support of energy efficiency for residential buildings and home appliances, its efficiency standards were relatively low compared to those applied in western developed countries. Perhaps more critically, China's monitoring and enforcement of energy efficiency standards and labels were relatively weak. Few policies directly targeted consumers' energy consumption behaviors. Still, in the summer of 2007, China's state council required all government agencies to set their thermostats no lower than 26 degree Celsius in public buildings. Nonetheless, this environmental edict was largely ignored by provinces and cities outside of Beijing and even some local officials within Beijing (Friedman, 2008). Household-targeted policies about rational energy consumption remain a missing component in China. Thus, a study of households' energy consumption behavior is undoubtedly very important to inform energy policy.

2.6 Summary

Household energy consumption increases in both developed and developing countries even with significant energy efficiency improvements and strict energy price regulation. Rebound effects partly explain why total household energy consumption rises when energy efficiency of the production sector improves. However, this theory only concerns technological change and neglects the effect of changing consumer demand towards higher living standards. Sustainable consumption indicates a research framework as well as directions of desired changes of household consumption behavior. Empirical studies examine household energy consumption patterns of specific countries or regions and explore key factors that affect household energy consumption.

Most of studies of household energy consumption in China focus on the direct energy consumption factors such as the transition of the fuel mix and changes in end use structures. Studies of total energy consumption (both direct and indirect) are mainly macro-level analyse based on I-O models. The indirect energy consumption patterns of urban and rural households are calculated and compared at both national and regional levels for certain years. However, a long-term and spatial analysis of household energy consumption in China is missing. These studies cannot display a clear picture of how lifestyle changes from poverty to a relatively well-off society have impacted household energy consumption in China. Some studies use household survey data to explore household energy requirements. Most of them are descriptive analysis of one or several cities or counties. Few studies explore the driving factors that impact household energy requirements at the micro-level. Thus there appears to be room for improvement that could contribute to temporal and spatial analysis in the macro-level as well as micro-level analysis to form a more complete understanding of household energy consumption in China.

Chapter 3

National Level Analysis of Household Indirect Energy Use

3.1 Introduction

As the largest developing country in the world, China has enjoyed near double-digit annual economic growth during the past three decades. To support such rapid economic growth, China's energy consumption has increased fivefold from 603 million tons of coal equivalent (Mtce) in 1980 to over 3 billion tce in 2009 (National Bureau of Statistics of China (NBS), 2010). In 2009, the nation consumed 17.3% of the world's energy compared to 7.9% in 1973, making it the world's largest energy consumer and top greenhouse gas emitter (Guan et al., 2009; Minx et al., 2011).

China is a developing country with growth that relies heavily on it booming industrial sector. During the past three decades, its economic growth has been driven by capital investment to develop an export-based economy. The role of household spending decreased from 50.8% in 1980 to 33.8% in 2010. Compared with other countries, China has a very low share of household consumption in GDP. In 2009, household consumption accounted for only 35.6% of GDP in China, compared to 71.1% in USA and 57.5% in India (OECD, 2013). During the past three decades, China's households have experienced a huge lifestyle change from one of poverty to one that fulfills basic household needs with hopes of pursuing a higher living standards (Hubacek et al., 2011, 2007).

Per capita annual disposable income for urban residents increased at an average annual rate of 7.0% from 2,514 Yuan in 1980 to 19,109 Yuan in 2010 (constant 2010 prices). For rural residents, it rose 6.6% annually from 862 Yuan to 5,919 Yuan. With increased disposable income, residential direct energy use per capita rose at an average annual rate of 3.4% from 106.6 kg standard coal equivalent (SCE) in 1983 to 254.2

kg SCE in 2009 (NBS, 2011). However, growth at the residential energy consumption has been lagging total energy use in China, as a result, the residential share of energy use decreased from 19.8% in 1987 to 11.2% in 2007 (see *Figure* 3.1). The low share of household consumption of GDP and low share of residential direct energy use points out why China's energy conservation policies have focused on industries but largely neglected households.

The current export- and capital investment-lead economy is not sustainable. To balance its economic structure and recover from its economic slow down, Beijing is encouraging growth in domestic demand with the help of its fast-rising household income. That is, it is backing off its policy of encouraging savings and instead embracing a Western-style consumer society. Thus the nation's ongoing urbanization and income-driven lifestyle change should cause energy consumption related to the household sector to rise significantly. As shown in *Figure* 3.2, residential direct energy use in China is 261 kg oil equivalent per capita, 71% of the Japan's level and only 30.6% of that in the USA. It is natural to ask whether residential energy consumption growth in China will follow the Japanese model, the American model, or some other trajectory. Considering its high population density, severe energy security problem, and environmental pressures, China needs to pursue a model with deep energy savings. Thus, it seems prudent to understand past trends in household energy use.

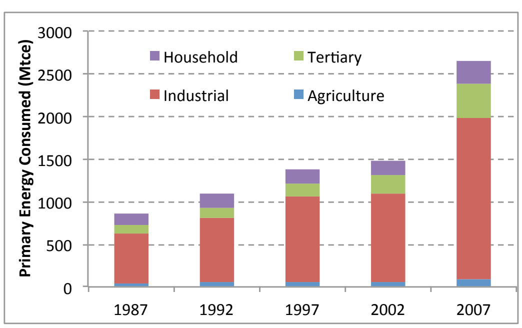


Figure 3.1: Total Energy Use in China (1987-2007)

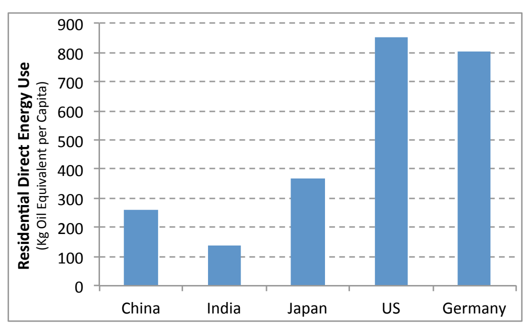


Figure 3.2: Per Capita Residential Direct Energy Use in 2009 (IEA, 2012)

This chapter is organized as follows. Section 2 outlines the research approach. Section 3 generally describes trends in Chinese households' direct and indirect energy use. Direct energy use refers to energy used directly in the home for daily activities while indirect energy use refers to energy embodied in the goods and services that are consumed by residents. Section 3 digs deeper to explore the driving forces of household energy use. Here we discuss the results of structural decomposition analysis of changing household indirect energy use in China. A final section concludes this chapter and offers policy suggestions for Beijing to guide its residents' lifestyles toward more sustainable living.

3.2 Method

Input-output (I-O) analysis has long been used in energy and energy-induced emission analysis (as early as Cumberland (1966) and Leontief (1970) and as recently as Kagawa's (2011) book, which contains a solid review of the extent literature as well as many new extensions). The economywide energy burden stemming from household spending can be expressed mathematically as

$$E = \mathbf{e}'(\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} = \mathbf{e}'\mathbf{L}\mathbf{y} \tag{3.1}$$

where E is a scalar representing total energy embodied in goods and services that consumed by households; $\mathbf{e}'$ is a vector with e_i as energy input per unit of output of industry i ($n\times1$ vector with n represents the number of industrial sectors); $\mathbf{L} \equiv (\mathbf{I} - \mathbf{A})^{-1}$ is known as the Leontief-inverse matrix ($n\times n$ matrix) which shows total input requirements; $\mathbf{I}$ is the identity matrix ($n\times n$ matrix); $\mathbf{A}$ is a matrix showing the monetary relationship between different sectors in the economy ($n\times n$ matrix); and $\mathbf{y}$ is a vector of final demand spending on each sector by households ($n\times1$ vector).

Based on Eq.3.1, we calculate indirect energy use for both rural and urban households. Considering the differences between urban and rural areas, we disaggregate household spending into total urban household spending and total rural household spending and using $\mathbf{y}_H$ ($n\times2$ matrix) to replace $\mathbf{y}$. Since total population changes over years, we decompose household spending $\mathbf{y}_H$ into per capita urban and rural household spending $\mathbf{H_p}$ ($n\times2$ matrix) and the population for rural and urban households $\mathbf{p}$ (2×1 vector) with $\mathbf{y}_H = \mathbf{H_p} * \mathbf{p}$. We further decompose $\mathbf{H_p}$ and $\mathbf{p}$ into structure and volume components with $\mathbf{H_p} = \mathbf{Hs} * \mathbf{Hv}$ and $\mathbf{p} = \mathbf{u} \circ \tau$.[1] $\mathbf{u}$ indicates the shares of urban and rural population of total population ($n \times 2$ matrix) and τ shows the total population (scalar).

Structural decomposition analysis is the analysis of economic change using a set of comparative static changes in key parameters of input-output tables (Rose and Miernyk, 1989). Thus changes in household indirect energy use can be disaggregated into six partical contributing factors: changes in total population ($\Delta\tau$), changes in urbanization level ($\Delta\mathbf{u}$), changes in energy efficiency ($\Delta\mathbf{e}'$), changes in input structure ($\Delta\mathbf{L}$), per capita household consumption structure ($\Delta\mathbf{Hs}$) and per capita household consumption level ($\Delta\mathbf{Hv}$). Using multiplicative structural decomposition analysis (SDA) framework, changes in household indirect energy use can be write as:[2]

$$
\begin{aligned}
\frac{E_1}{E_0} &= \frac{\mathbf{e'}_1\mathbf{L}_1(\mathbf{Hs}_1\mathbf{Hv}_1)(\mathbf{u}_1 \circ \ \tau_1)}{\mathbf{e'}_0\mathbf{L}_0(\mathbf{Hs}_0\mathbf{Hv}_0)(\mathbf{u}_0 \circ \tau_0)} \\
&= (3.2a) \times (3.2b) \times (3.2c) \times (3.2d) \times (3.2e) \times (3.2f) \\
&= \frac{\mathbf{e'}_1\mathbf{L}_1(\mathbf{Hs}_1\mathbf{Hv}_1)(\mathbf{u}_1 \circ \tau_1)}{\mathbf{e'}_0\mathbf{L}_1(\mathbf{Hs}_1\mathbf{Hv}_1)(\mathbf{u}_1 \circ \tau_1)} && \text{(3.2a)} \\
&\times \frac{\mathbf{e'}_0\mathbf{L}_1(\mathbf{Hs}_1\mathbf{Hv}_1)(\mathbf{u}_1 \circ \tau_1)}{\mathbf{e'}_0\mathbf{L}_0(\mathbf{Hs}_1\mathbf{Hv}_1)(\mathbf{u}_1 \circ \tau_1)} && \text{(3.2b)} \\
&\times \frac{\mathbf{e'}_0\mathbf{L}_0(\mathbf{Hs}_1\mathbf{Hv}_1)(\mathbf{u}_1 \circ \tau_1)}{\mathbf{e'}_0\mathbf{L}_0(\mathbf{Hs}_0\mathbf{Hv}_1)(\mathbf{u}_1 \circ \tau_1)} && \text{(3.2c)} \\
&\times \frac{\mathbf{e'}_0\mathbf{L}_0(\mathbf{Hs}_0\mathbf{Hv}_1)(\mathbf{u}_1 \circ \tau_1)}{\mathbf{e'}_0\mathbf{L}_0(\mathbf{Hs}_0\mathbf{Hv}_0)(\mathbf{u}_1 \circ \tau_1)} && \text{(3.2d)} \\
&\times \frac{\mathbf{e'}_0\mathbf{L}_0(\mathbf{Hs}_0\mathbf{Hv}_0)(\mathbf{u}_1 \circ \tau_1)}{\mathbf{e'}_0\mathbf{L}_0(\mathbf{Hs}_0\mathbf{Hv}_0)(\mathbf{u}_0 \circ \tau_1)} && \text{(3.2e)} \\
&\times \frac{\mathbf{e'}_0\mathbf{L}_0(\mathbf{Hs}_0\mathbf{Hv}_0)(\mathbf{u}_0 \circ \tau_1)}{\mathbf{e'}_0\mathbf{L}_0(\mathbf{Hs}_0\mathbf{Hv}_0)(\mathbf{u}_0 \circ \tau_0)} && \text{(3.2f)}
\end{aligned}
$$

Where

$\Delta\mathbf{e}'$: effect of changes in energy requirements per unit of output (Eq: 3.2a);

$\Delta\mathbf{L}$: effect of changes in inter-industrial input structure (Eq: 3.2b);

$\Delta\mathbf{Hs}$: effect of changes in per capita household consumption pattern (Eq: 3.2c);

[1] Here, $\circ$ denotes Hadamard product (element-by-element multiplication of matrices).

[2] Here only shows one side of the polar decomposition. This dissertation examine both polar decompositions and use Fisher indexes to analyze results. Fisher indexes are obtained by taking the geometric average of corresponding elements of the two polar decompositions (Dietzenbacher et al., 2000).

$\Delta\mathbf{Hv}$: effect of changes in per capita household consumption level (Eq: 3.2d);

$\Delta\mathbf{u}$: effect of changes in the share of urban population of total (Eq: 3.2e);

$\Delta\tau$: effect of changes in total population (Eq: 3.2f).

This research is based on three types of data: national I-O tables, energy consumption data, and demographic data. Here we use the I-O tables for 1987 (118 sectors), 1992 (119 sectors), 1997 (124 sectors), 2002 (122 sectors), and recently released 2007 (135 sectors), all compiled by the Chinese National Bureau of Statistics (NBS, 1991; 1995; 1999; 2006; 2009). To maintain consistency in this study, we aggregate all I-O tables to 84 industrial sectors. Also, all tables are adjusted to the 2007 constant prices to make them comparable and to avoid discussion of the effect of changes in relative prices (see Yang and Lahr (2010) for a detailed discussion[3]). The energy data were taken from China's Energy Statistical Yearbook (NBS, 1990; 1998; 2001; 2004; 2008). The 1987 and 1992 energy data contain 23 industrial sectors and energy data for other corresponding years use 44 industrial sectors. Similar to Peters et al. (2007), we map the energy data to 84 economic sectors used in the I-O tables through a concordiance matrix. The demographic data of urban and rural population is from China Statistical Yearbook (NBS, 2011).

3.3 Residential Energy Use

From 1987 to 2007, household direct energy use[4] rose gradually at an average annual rate of 3.4% from 137.9 Mtce in 1987 to 267.9 Mtce in 2007 (See *Figure* 3.3). The aggregated indirect flow of energy into Chinese households is larger than the aggregated direct flow. *Figure* 3.3 shows the energy requirements of all urban and rural households in an effort to focus on volume trends in energy flows. From 1987 to 2007, aggregate direct energy use rose 76.6% for rural households and 107.9% for urban households. However, indirect energy use decreased 12.6% for rural households but increased 253.9%

[3]As suggested by Yang and Lahr (2010), this chapter uses the agriculture producer price index for the primary sector and the free-on-board price index for the secondary sector to adjust prices. For the tertiary and construction industries, an implicit GDP price index (Nominal GDP divided by real GDP of these industries) was used.

[4]The direct energy use mentioned above is direct use of commercial energy.

for urban households over the same period. The differential trends for urban and rural household energy use was partly caused by rapid urbanization in China during these two decades. Between 1987 and 2007, total population in China rose 20.9% from 1.09 billion to 1.32 billion with its total urban population increased 119.1%, while its total rural population decreased 12.4%.

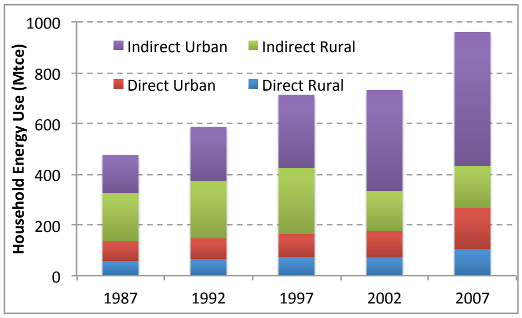


Figure 3.3: Resident's Direct and Indirect Energy Requirements

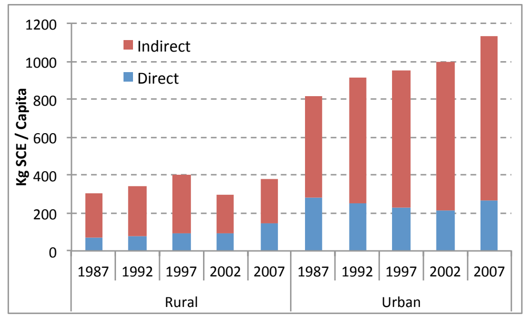


Figure 3.4: Per Capita Resident's Direct and Indirect Energy Requirements

3.3.1 Residential Direct Energy Use

From 1987 to 2007, rural households direct energy use per capita rose gradually at an average annual rate of 3.6% from 73 kg SCE to 148 kg SCE. For urban households, direct energy use per capita decreased from 282 kg SCE in 1987 to 211 kg SCE in 2002. It rose to 267 kg SCE in 2007. The direct energy use here only refers to commercial energy. Non-commercial energy sources such as firewood, straw and biogas are also important energy sources for rural residents. In 2007, the average noncommercial energy use per capita for rural residents was 357 kg SCE. Thus, rural households consumed far more direct energy when non-commercial energy is considered.

From 1987 to 2007, the fuel mix of Chinese households changed dramatically. Direct use of coal in households fell steadily as more urban residents moved to units with central heating and switched to electricity for cooking and water heating. Coal's share decreased from 85% in 1987 to 21% in 2007. The sources of direct household energy use became more diversified: heat, liquefied petroleum gas (LPG), and natural gas became more widely used. As China electrified, electricity replaced coal in homes. It's share rose from 8% in 1987 to 53% to 2007. The timing of substitution was different for urban and rural areas. During the two decades through 2007, per capita urban household direct use of coal dropped from 328 kg to 35 kg, while per capita rural household direct use of coal edged down slightly from 91 kg to 83 kg (see *Figure* 3.5). Electricity rapidly penetrated the daily lives of both urban and rural households. From 1987 to 2007, per capita electricity usage increased from 59 kWh to 368 kWh for urban residents, and from 15 kWh to 197 kWh for rural residents (see *Figure* 3.6). The decreasing direct use of coal in homes significantly improved indoor air-quality. Also, the increasing usage of LPG and natural gas in urban household has improved air quality in large cities across China.

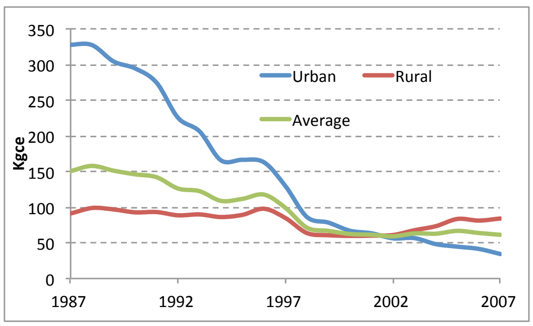


Figure 3.5: Per Capita Direct Use of Coal in homes in China, 1987-2007

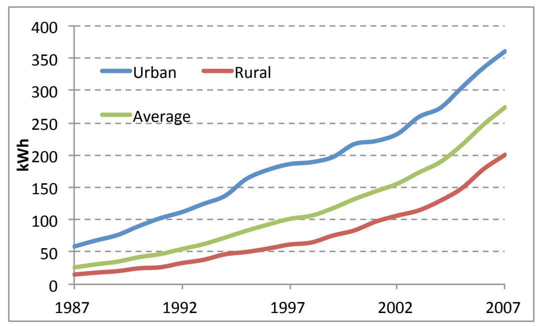


Figure 3.6: Per Capita Direct Use of Electricity in home in China, 1987-2007

Compared to their rural counterparts, urban residents used greater share of alternative fuels such as natural gas, heat and, LPG. Urban residents nearly fully replaced coal through the use of electricity, natural gas, and LPG. Households in rural areas have more work ahead. Also, in some poor rural areas that have limited access to electricity, coal continues to replace some non-commercial energy sources, such as firewood and other biomass (*e.g.* straw) as an important energy source for cooking and heating. This may explain why the direct coal use for rural residents fluctuated a bit during these 20 years.

Although the gap in direct energy use per capita between urban and rural residents shrank, an urban resident still used 81% more energy than did a rural resident in 2007. Indeed, the direct energy used by urban residents increased rapidly from 2002 to 2007 with no sign of relenting. Rural residents showed even higher demand for direct energy use, converging on use rates of their urban counterparts. Hence, it seems per capita residential direct energy use will continue to rise in both urban and rural China.

3.3.2 Residential Indirect Energy Use

In 1987 and 2007, energy embodied in goods and services by a rural resident remained fairly constant 232 kg SCE. During these two decades, rural households experienced huge changes in such embodied way. It rose at an average annual rate of 2.9% from 1987 to 1997. It then decreased at an average annual rate of 8.2% from 1997 to 2002. It then rose again, this time at an average annual rate of 2.8% from 2002 to 2007. For urban households, indirect energy use rose steadily at an average annual rate of 2.4% from 537 kg SCE in 1987 to 868 kg SCE in 2007. From 1987 to 2007, the gap of per capita indirect energy use between urban and rural households enlarged. In 1987, an urban resident consumed 131.4% more indirect energy through goods and services than his rural counterparts. In 2007, the average resident living in urban China consumed 274.6% more indirect energy than the average resident who lived in rural China.

Both rural and urban households consumed more commercial energy indirectly than directly during the past two decades. This is undoubtly due to the rising purchasing power of China's households. In 2007, indirect energy accounted for 61.0% of total household energy use for rural households and 76.4% for urban households. Combining both direct and indirect energy use, households accounted for a larger part of total energy use in China. It is clear that it is very important for China to take households into account when identifying energy reduction options. Thus, it is very important to diagnose the driving forces of changes in trends for household indirect energy use.

3.4 The Contributions of Different Drivers to Household Indirect Energy Use

In the 20 years from 1987 to 2007, indirect energy use by China's household increased 104.6% from 338.1 Mtce to 691.8 Mtce. It increased at an average annual rate of 5.4%, 4.5%, and 4.6% during the 1987-1992, 1992-1997, and 2002-2007 periods. From 1997 to

2002, it stagnated growing at the level of only 0.1% annually. Our structural decomposition analysis shows that per capita household consumption ($\Delta\mathbf{Hv}$) drives the increase, although energy efficiency improvements ($\Delta\mathbf{e}'$) offset a large part of the increment from 1987 to 1997. From 1997 to 2007, energy efficiency improvements actually fully offset the increment caused by the rising per capita household consumption (see *Figure* 3.7).

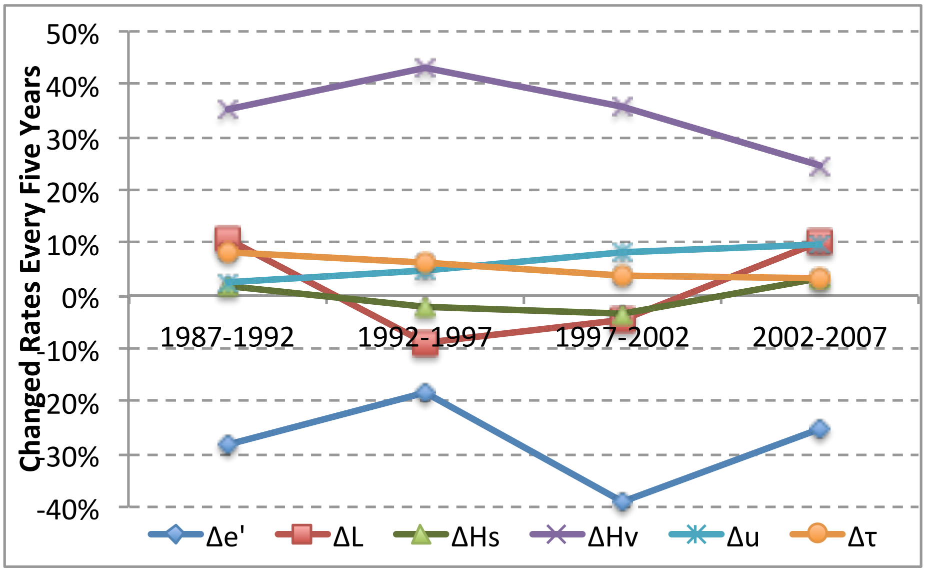


Figure 3.7: Driving Forces of Household Indirect Energy Use

Energy efficiency improvements ($\Delta\mathbf{e}'$) helped reduce households' indirect energy use by 4.0% to 6.4% annually during the 1987-1997 and 2002-2007 periods. However, from 1997 to 2002, energy efficiency improvements reduced household indirect energy use by 9.5% annually. Increasing household consumption levels ($\Delta\mathbf{Hv}$) drove energy use to rise at an average annual rate of 6.2% during the 1987-1992 period. Its effect surged to 7.4% annually in the 1992-1997 period. Then, it decreased gradually to 4.5% annually in the 2002-2007 period.

Changes in production structure ($\Delta\mathbf{L}$) and in the type of purchases made by household ($\Delta\mathbf{Hs}$) had relatively little effect on changes in household indirect energy use. From 1987 to 1992, changes in production structure and household consumption structure enhanced household indirect energy use. During the 1992 to 2002 period, both of these factors reduced indirect energy use. However, from 2002 to 2007, changes in production structure and household consumption structure actually caused household indirect energy use to rise at an average annual rate of 1.9% and 0.7%, respectively.

Population growth ($\Delta\tau$) and urbanization ($\Delta\mathbf{u}$) increased household indirect energy use from 1987 to 2007. As population growth moderated when the one-child law was enforced, its effect decreased gradually from 1.5% annually in the 1987-1992 period to 0.6% in the 2002-2007 period. Meanwhile, urbanization's effect became stronger, rising from 0.5% to 1.9%. Demographic factors, especially urbanization became a major factor driving household indirect energy use in China. By focusing on the most recent 2002-2007 period, we discuss these driving factors by following four sections.

3.4.1 Household Consumption Level

With rapid economic growth, China's household income increased steadily in both urban and rural areas. Average per capita income rose at an average annual rate of 7.5% from 3,216 Yuan in 1987 to 13,786 Yuan in 2007 in urban China while but just 4.8% annually from 1,611 Yuan to 4,140 Yuan in rural China (Constant 2007 Price). Clearly, huge urban and rural disparities in average per capita income persist. In 2007, average per capita income in urban China was 233% higher than in rural China. With rapid income growth, Chinese households experienced significant lifestyle changes that led them to demand more energy and less pollution. That is people's lifestyles in China changed from fulfilling basic needs toward pursuing higher living standards. In the following, we demostrate the lifestyle changes in China by examing four aspects: housing, ownership of home appliances, space heating and cooling and personal mobility.

Housing

Since the early 1980s, China's housing reform successfully transformed urban China's housing from a public-sector dominated system to a market-oriented housing industry (Deng et al., 2011). As a result, urban housing shortages of urban residents have greatly diminished. Also, the living conditions of urban residents have been greatly improved. Average living space per capita expanded dramatically from 1987 to 2007, from 12.7 m^2 to 30.1 m^2 in urban China and from 16 m^2 to 31.6 m^2 in rural China (see *Figure* 3.9). Many rural households rebuilt or expanded their housing, using more material-and energy-intensive building materials in the process. For newly built rural houses, the share of brick and wood structure buildings declined from 65% to 26%, while the share of reinforced steel and concrete structures rose from 8% to 70%. Chinese households' desire to improve their living conditions drove China's construction boom. From late 1990s to 2004, China added about 1.5 to 2.0 billion m^2 of space annually to its building stock. This trend is expected to continue through 2020 (Fernández, 2007). Residential buildings are expected to accounted for about 80% of all new construction.

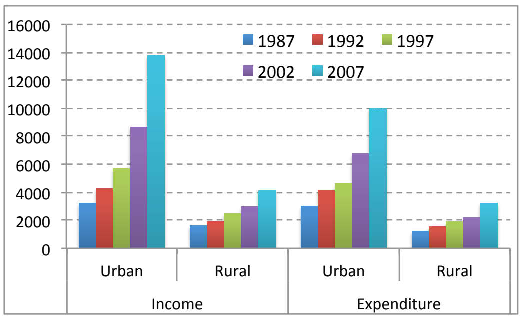


Figure 3.8: Per Capita Household Income and Expenditure in China

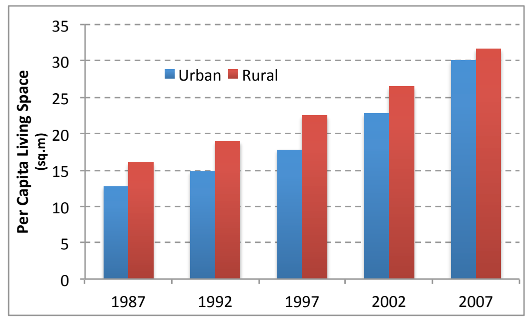


Figure 3.9: Per Capita Living Space in China from 1987 to 2007

Home Appliances

Increasing income and more living space allowed Chinese households to buy more home appliances. During the past three decades, increased access to the electric grid facilitated the penetration of electrical home appliances in both urban and rural China. From 1985 to 2010, the rate of durable goods ownership increased rapidly in both urban and rural China (see *Table* 3.1 and *Table* 3.3). Color television ownership has almost saturated households in both urban and rural China. In fact, many households have more than one television. Ownership of washing machines, refrigerators, and air conditioners is close to saturation in urban China. In rural area, the ownership of these three types of appliances is much lower. In 2010, about 112 air conditioners existed per every 100 urban households, but only 16 were owned per every 100 rural households. Compared with traditional electrical appliances, information technology appliances such as computers and mobile phones penetrated Chinese households faster during the past decade. In 2000, only a small share of Chinese households had mobile phone. Now, mobile phones dominate communications even in rural China. From 2000 to 2010, ownership of computers rose from 9.70 sets to 71.16 per 100 household in urban China and from 0.47 to 10.37 per 100 rural household. Modern home appliances, previously a luxury became a normal good in Chinese households' daily lives. The collective demand surge in home appliance ownership is a primary driving force in the rise in household electricity usage (Glicksman et al., 2001). Home appliances will continue to push electricity needs per capita upward in China.

Table 3.1: Average Durable Goods Ownership per 100 Families in Urban China

Year	1985	1990	1995	2000	2005	2010
Color television	17.21	59.04	89.79	116.6	134.8	137.43
Washing machine	48.29	78.41	88.97	90.5	95.51	96.92
Refrigerator	6.58	42.33	66.22	80.1	90.72	96.61
Air conditioner	-	0.34	8.09	30.8	80.67	112.07
Mobile phone	-	-	-	19.50	137.00	188.86
Personal computer	-	-	-	9.70	41.52	71.16
Car	-	-	-	0.50	3.37	13.07

Table 3.2: Average Durable Goods Ownership per 100 Families in Rural China

Year	1985	1990	1995	2000	2005	2010
Color television	0.80	4.72	16.92	48.74	84.08	111.79
Washing machine	1.90	9.12	16.90	28.58	40.20	57.32
Refrigerator	0.06	1.22	5.15	12.31	20.10	45.19
Air conditioner	-	-	0.18	1.32	6.40	16.00
Mobile phone	-	-	-	4.32	50.24	136.54
PC	-	-	-	0.47	2.10	10.37
Personal computer	-	0.89	4.91	21.94	40.70	59.02

Heating and Cooling

In 1999, energy used in buildings accounted for 27.8% of all energy used in China in 1999. With ongoing urbanization, this share is estimated to grow to about 35% in 2030, a share more typical of developed countries (Zhu and Lin, 2004). Energy used in space heating and cooling accounted for a major part of all residential energy use. As a spacious country, China has a northern heating zone, central transition zone, and a southern zone. In the heating zone, urban households have access to central heating. The transition zone, with cold winters and hot summers, has a significant demand for space heating in winter and cooling in summer. In the southern zone, the demand for cooling is significant (Glicksman et al., 2001). As Chinese residents getting richer, households throughout the nation will demand more comfortable indoor tempeartures. Presently, central heating is only available to urban residents in the heating zones. For those in transition zones, with 37% of China's residential floor area, the demand for space heating is expected to rise dramatically in the near future (China Green Buildings Blog, 2009). Air conditioning is largely used in hot humid weather. In the summer of 2000, about a quarter of the peak electricity demand was used for air conditioning in Shanghai (Glicksman et al., 2001). In 2004, more than 60% of cities in China experienced an electricity shortage during peak summer air conditioning period (Aldhous, 2005). As air conditioner ownership penetrates rural China, the demand of electricity through the use of air conditioners will continue to cause electricity demand to surge.

Building energy efficiency is presently low in China. Although the China Ministry of Construction has been actively engaged in design and dissemination of energy conservation building codes, enforcement of these codes has been fairly lax. Many new Chinese buildings do not meet energy standards established by the Ministry of Construction. Even in Beijing, where stricter regulation and implementation of building energy efficiency has been established, residential buildings consume 50-100% more energy for space heating compared with buildings in similar climate zones of Western Europe or North America, while providing far less thermal comfort (Zhu and Lin, 2004). In most of China's heating zone, heating is billed based on floor space rather than on actual usage. Moreover, households have little control over their housing's temperature and heat usage. Perhaps worst of all, residential heating is largely subsidized by the national and local government. So incentives are perverse or absent. On the production side, the energy efficiency of central heating systems is low for heat generation and distribution. From the consumption side, households usually have few incentives and little cability to reduce their heating usage. As a result, low building energy efficiency and heating provision system have lead to an enormous energy inefficiencies in China.

Personal Mobility

Over the past three decades, personal mobility in China has risen. From 1987 to 2007, the total motorized passenger-kilometers increased at an average annual rate of 7.7% from 491 billion to 2,159 billion km. Motorized km *per capita* more than tripled, rising from 45.0 km/year in 1987 to 163.4 km/year in 2007. The use of civil aviation and highways increased even more rapidly (see *Figure* 3.10). Rising disposable income has boosted the rapid penetration of cars among Chinese households. Per household private car ownership in urban China sky rocketed from 0.88 units per 100 households in 2002 to 6.06 units per 100 households in 2007. This rapid growth continued through the global financial crisis in 2008, as the ownership rate has jumped to 13.07 units per 100 urban households in 2010. Car ownership becomes a sign of wealth and assumes higher social status in China. But it also has lead to an increase in the demand for petroleum products. In China, the resources for petroleum-based fuels are largely imported. Imports account for about two thirds of the nation's total oil consumption (NBS, 2010). The increasing demand for fuel will severely cause a crisis with respect to China's energy security. If the current rising trend of ownership of private cars continues, Han and Hayashi (2008) estimated that the emissions of CO_2, CH_4, CO, NMVOC, NO_x and SO_2 that caused by private cars in 2020 will be 16 to 20 times than their 2000 level. Thus, China should be very concerned about its increasing ownership of private vehicles and be more firm in enforcing any policies pertainning to fuel consumption.

3.4.2 Composition of Household Consumption

From 1987 to 2007, per capita annual expenditures for urban residents increased at an average annual rate of 7.6% from 2,331 Yuan to 9,997 Yuan (constant 2007 prices). For rural residents, it rose 4.8% annually from 1,255 Yuan to 3,224 Yuan. The share of spending on core necessities –food and clothing– by all households, decreased from around 65% in 1987 to about 47% in 2007. Expenditures on health care, transportation

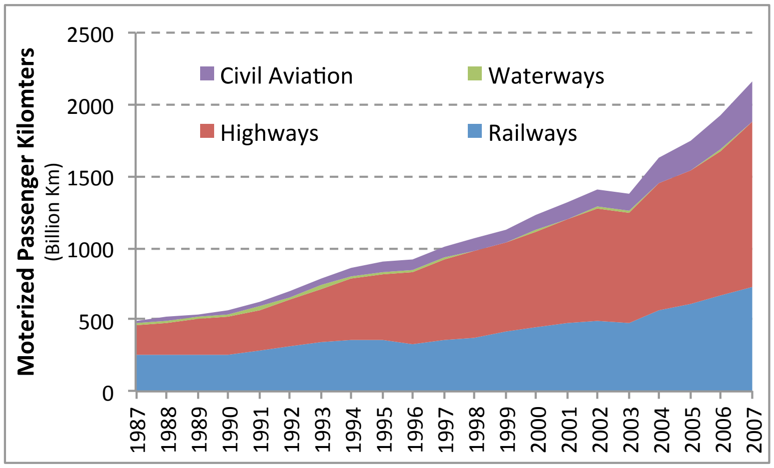


Figure 3.10: Total Moterized Passenger Kilometers in China

and communication services meanwhile increased from 1987 to 2007. Chinese households are clearly pursuing a more comfortable style of living that requires a developed service sector.

The nature of the lifestyle changes affected households' indirect energy consumption. The increased share of spending on services partly explains why the changes in households' consumption structure reduced indirect energy use from 1997 to 2002. However, composition of household consumption changes increased indirect energy use of households' at an average annual rate of 0.7% from 2002 to 2007. During this period, Metal smelting, pressing and metal products accounted for 28% of the rise in per capita indirect annual energy use of urban residents and 23% for rural residents. Clearly, households' rising consumption of living space and ownership of home appliances, mentioned earlier section explain much of such indirect use. As suggested above, service sectors accounted for about 40% of the rise in indirect energy use by households in both urban and rural China from 1997 to 2007. Most of increase happened through rises in the Wholesale, retail and postal sector (18% in urban area, 24% in rural area) and the Transportation service sector (11% in urban area and 14% in rural China). This reflects the increased purchasing capacity and enhanced extent of interregional trade in China, especially by rural China. Per capita household indirect energy use from the Petroleum, chemical and non-chemical mineral sector rose 10.1 kg SCE for urban residents from 2002 to 2007. A large part of this increment was undoubtedly caused by the rising use of privately owned cars, which concentrated in urban China. The ongoing penetration of home appliances also caused rises in indirect energy use by the Utility sector, which accounted for 7% of the total rise for urban China and 18% for rural China. The Food and tobacco products sector accounted for 7% of increment of per capita indirect energy use of urban residents. This increment likely reflects the increasing demand for processed food, particularly meat, in urban China. Fundamentally, recent trends in indirect energy use suggest that households have been increasingly shifting their consumption toward more energy- and material-intensive goods and services. Also, the demand for a more convenient life (with improved personal mobility, interior climate control, and time-saving appliances and goods) is likely to drive household consumption to become even more energy-intensive in the future.

Table 3.3: Per Capita Household Indirect Energy Use in China from 2002 to 2007

Sector	Urban			Rural		
	2002	2007	02-07	2002	2007	02-07
Agriculture	52.9	57.0	4.1	23.5	24.5	1.0
Mining	69.4	65.0	-4.3	17.3	16.5	-0.8
Food & Tobacco products	34.7	42.0	7.3	11.0	12.1	1.0
Textile Products	23.5	28.3	4.8	4.6	6.4	1.8
Sawmill, Paper, Printing & Recreation Goods	21.1	22.2	1.1	4.9	5.2	0.3
Petro-, Chemical & Non-metal Mineral Products	232.3	242.4	10.1	61.4	62.3	0.9
Metal Smelting & Pressing, Metal Products	90.4	119.3	28.9	20.8	26.6	5.8
Machinery & Transportation Equipment	13.1	14.1	1.0	3.3	3.2	0.0
Electric & Electronic Products	9.0	10.4	1.4	1.6	2.4	0.8
Other Manufacturing	8.4	6.7	-1.7	1.6	1.3	-0.3
Utilities	95.7	103.1	7.3	20.1	24.6	4.5
Construction	0.8	1.5	0.7	0.2	0.1	-0.1
Transportation	43.9	55.8	11.8	10.7	14.1	3.5
Wholesale, Retail, & Postal Services	49.6	68.4	18.8	10.7	16.7	6.0
Finance, Insurance & Real Estate	16.6	21.5	4.9	4.1	4.3	0.3
Other Service	21.3	28.5	7.2	6.4	7.2	0.9
Total	782.7	886.1	103.4	202.2	227.6	25.4

3.4.3 Demographical Changes

From 1987 to 2007, China's total population rose 1.0% annually from 1.09 billion to 1.32 billion. This growth was outpaced by the number of households, which increased 2.0% annually from 248.4 million to 367.3 million. The divergence between the growth of population and the number of household is caused by decreased household size. The average household size declined from 4.23 people in 1987 to 3.17 in 2007. China's urban population increased its share of China's total population from 25.3% in 1987 to 45.9% in 2007. Such demographic changes manifest in household consumption patterns through several different pathways. First, with rapid urbanization, the geographical expansion of large cities and newly formed polycentric urban zones dramatically increased the demand for transportation infrastructure (Fernández, 2007). Second, due to the huge gap between urban and rural residents in per capita household energy usage, urbanization in the foreseeable future will continue to significantly enhance the total household energy demand, both directly and indirectly. Third, small households consume more energy and resources per capita. Thus China's shift to smaller households poses a serious challenge to energy conservation as well as for other issues relating to elder care (Liu et al., 2003; Liu and Diamond, 2005). In summary, the combined demographical trends of increasing urbanization and ever-smaller household sizes will continue to enhance household energy use in the long run.

3.5 Conclusions and Outlook

Rising disposable incomes in China have induced household energy use to increase 102% between 1987 and 2007. The gap in energy use between urban households and rural households grew. In 2007, an average urban resident consumed 80% more energy than their rural counterparts directly (267 kg SCE versus 148 kg SCE). They consumed 274 percent more indirect (868 kg SCE versus 232 kg SCE). This gap in household energy use suggests that the potential for energy use by Chinese rural households is high. Increases in living space, electric appliance ownership, the demand for heating and cooling, and personal mobility characterizes the China's burgeoning residential sector.

Its lifestyle changes are likely to increase energy use by inducing changes in China's production structure. Although industrial energy efficiency gains have offset household consumption rises, demographic changes and the aforementioned production and consumption structure changes will undoubtedly continue to push households' indirect energy use in the long run. Our research yields some interesting policy suggestions that follows:

First, Chinese households were "moving up" the consumption ladder as their income increased. China's newly formed middle class has been emulating a Western lifestyle with the purchase of cars, bigger homes, and complete a cadre of labor-saving devices. Rural households have been lagging their urban counterparts. Still, this also means they have more potential to increase energy demand if they continue a desire to emulate their urban counterparts. Guiding Chinese residents' lifestyles toward more sustainable consumption will be a critical strategy for future energy conservation in China. The Chinese government should co-ordinate cross-sector policies that may have potential environmental impacts on household decisions (e.g. land-use, infrastructure investment, and relevant macro-economic policies) to give consumers a stronger and more consistent set of signals and incentives to engage in sustainable consumption.

Second, low energy efficiency in buildings and heating systems in China have lead to much wasted energy in China. The enforcement of energy conservation through building codes is fairly low in China. Government must play a stronger role in the regulation, and more importantly, the enforcement of such codes if it seriously wants to improve energy efficiency. For existing building stock, Glicksman et al. (2001) suggest increasing insulation levels in walls and roofs, as well as installing double glass windows as a means of improving energy efficiency. Since buildings last for decades, renovations of this sort will pay back through the energy savings during their life cycle. The, Chinese government should deliver this sort of information to its citizens and provide incentives, such as low-interest loans, subsidies or information counseling to homeowners. The combined actions suggested above would very much improve the overall energy efficiency of China's residential building stock.

Third, in the heating zone, highly subsidized heating undermined producers' and consumers' incentives to save energy. Thus, government should at least adjust the price of heating to reflect its real costs, if not raise it above the real cost. In doing so, Beijing could also consider social equity for a subset of low-income households. Current billing systems based on the amount of living space size does not always actually reflect the real heating consumption. Also, residents of multi-family dwelling have little control of their indoor temperature except by opening and closing windows which creates a set of energy inefficiencies when heating is used. In the 11^{th} Five-Year Plan period (2005-2010), China retrofitted 0.15 billion m^2 of existing residential buildings with heat meter in northern heating areas (Zhao et al., 2009). The Chinese government should expand this heat meter program to the whole heating zone to liberalize central heating market and to improve energy efficiency.

Fourth, fuel substitution significantly improved China households' indoor air quality. Still, coal remains the dominant resource for generating electricity and central heating (Aldhous, 2005). Rising power and space heating demand will cause the demand for coal to consumption further. China's continued reliance on coal threatens to worsen the already notorious air quality in many of its cities. Thus, China should further encourage renewable energy and promote clean-coal technologies in power generation. Also, China should gradually switch from coal to more efficient and clean gas in space heating to scrub its filthy air in winter.

Last but not the least, sustainable household consumption requires the united effort of *government*, *households*, and *civil society*. Beijing should take a central, active role in promoting sustainable consumption by implementing regulations like stricter building codes and energy efficiency standards for electric appliances. Households' demand for environmentally sustainable products will concomitantly stimulate the supply of these products. Thus, if eco-labeling of buildings and home appliances and public awareness campaigns in energy conservation were highly promoted in China, households would become more aware of how to attain a more sustainable lifestyle. China also needs to become a civil society by encouraging NGOs to become information brokers for both corportations and households. They should be encouraged to do their good work of stimulating governments, corporations, and households to change their energy consumption behavior.

Chapter 4

Regional Level Analysis of Household Energy Use

4.1 Introduction

Energy use has stimulated China's economy. Like many large nations, China has great differences in economic development, energy endowment, energy consumption, demographics, and household consumption levels and patterns across its regions. It is well known that pronounced differences exist between its relatively developed Eastern Coastal regions and its less-developed Central and Western regions. The variations lead to regional discrepancies in household energy consumption. Thus, it could be very important to identify the main drivers of household energy use, and especially important in developing regional energy conservation policies.

Regional-level analysis in China typically focuses on regional disparities in energy efficiency and CO_2 emission intensity. China's regional energy efficiency is unbalanced too. Most of the nation's energy-efficient provinces are located on China's coast, while most of its least energy-efficient provinces are in its hinterland (Hu and Wang, 2006; Li and Hu, 2012; Liang et al., 2007; Wang et al., 2012; Wei et al., 2009; Yu, 2012). Wei et al. (2009) find that provincial energy efficiency is negatively associated with the share of secondary industry and state-owned economy in GDP while positively associated with technological level and the share of non-coal use in the region's fuel mix. A recent study by Feng et al. (2012) investigates drivers of regional CO_2 emission in China from 2002 to 2007 and found that there are significant gaps among eastern, central, and western China in CO_2 emissions intensities. Capital investment, rapid urbanization, exports, and inter-regional trade contribute substantially to changes in CO_2 emissions.

Few pieces have examined regional disparities in Chinese household energy-use patterns. Based on households' carbon footprints, Zheng et al. (2010) ranked 74 Chinese major cities and found that cities with cold Januarys tend to have higher household carbon emissions due to fuel and electricy usage. Feng et al. (2009) traced the lifestyle changes of five representative provinces in China: Shanghai, Guangdong, Henan, Heilongjiang, and Gansu. They found that recent household consumption change of all these five provinces were driven by enhanced income levels and the local supply of goods and services. There were considerable differences in household consumption patterns between coastal provinces (Shanghai and Guangdong) and inland provinces (Heilongjiang, Gansu). Dividing China into four regions: Eastern, Central, Western, and Northeastern, Feng et al. (2011) found that household indirect energy consumption and CO_2 emissions differ by region. The regional disparities in indirect energy use may be caused by differences in household income levels. All studies focus either only on selected cities or provinces or across short time periods. A comprehensive picture of household energy-use patterns across regionals remains still missing.

In this chapter, Mainland China is divided into eight regions to observe the disparities of household indirect energy use among regions as well as urban/rural differences within each region. Similar to the previous chapter, household energy use contains two parts: direct energy use and indirect energy use. Structural decomposition analysis is used to identify the drivers of household indirect energy use for each region from 1997 to 2007, as China's household lifestyles went through great transitions. Impacts of interregional trade of final goods and services to household indirect energy use of each region are also studied.

This chapter is organized as follows. Section 2 introduces the regional classification of this chapter and gives an overview of regional disparities of economic growth, energy endowment and consumption as well as population migration in China. Section 3 describes and discusses the regional disparities of household direct energy use through regional climate, space heating and cooling, and electric home appliance usage. Section 4 calculates regional disparities of per capita household indirect energy use and explores the driving forces of changes in household indirect energy use from 1997 to 2007 for each region. Section 5 concludes with several energy conservation policies related remarks.

4.2 Regional Economic Development and Energy Use in China

4.2.1 Regional Classification

In this chapter, China is divided into eight regions: Northeast China, North Municipalities, North Coast, East Coast, South Coast, Central China, Northwest China, and Southwest China (see *Figure* 4.1 and *Table* 4.1). As the major traditional industrial base of China, Northeast China (NE) has highly developed infrastructure and a high level of urbanization. Its heavy-industry based economy is facing issues of resource exhaustion and a need for upgrading its industrial structure. The North Municipalities (NM) includes Bejing and Tianjing. It is the political center and transportation hub of China. The North Coast (NC), including Hebei and Shandong, has a balance of light and heavy industry. The East Coast (EC) covers the Yangtze Delta area of China, with Shanghai as its center. This region has the highest level of economic growth with good public infrastructure and a bright financial and investment environment. The South Coast (SC) is well known for its agriculture and light industry of machinery and electronics. With the prestigious proximity to Hong Kong, Macao, Taiwan, and Southeast Asia, this region also has China's highest level of international trade and enjoys the highest level of foreign investment. Central China (CC) is densely populated with moderately developed agriculture and manufacturing industries. This region is particularly well endowed in agriculture, mineral, and energy resources. Northwest China (NW) is a remote inland area of China with low population density, few water resources, and inconvenient transportation. It has abundant energy and land resources. Southwest China (SW) is the least developed region and suffers from poor transportation access because of its physical mountainous geography. This area has abundant mineral and hydropower resources.

4.2.2 Economic Development, Energy Endowment and Energy Use

Figure 4.2 shows GDP per capita across those eight regions from 1987 to 2007. It should be clear that while the tide of income has risen for all, income disparity across the eight regions has expanded. Indeed, the gap in GDP per capita between the richest

Figure 4.1: The Eight Regions of China

region (NM) and the poorest region (SW) rose from 16,690 Yuan in 1997 to 40,710 Yuan in 2007 (constant 2007 Yuan). The rise in regional disparity was partly caused by China's regional economic policies (Fan, 1997; Li and Wei, 2010; Yang and Lahr, 2008). Since the Seventh national FYP, provinces in China were grouped into three economic zones: Eastern, Central, and Western.[1] The Eastern region had planned to develop export-oriented industries and foreign trade. The Central economic zone was to focus on agriculture and energy industries. And the Western economic zone was supposed to focus on animal husbandry and mineral exploitation (State Council of China, 1986). The "Coastal Development Strategy" of the 1980s and 1990s offered favorable policies such as tax abatements, and state funding for infrastructure development to the Eastern coastal economic zone with the hope of making it the "growth pole" of China. The

[1] Compared to the classification of regions in this chapter (see *Table* 4.1), the Eastern region contains the South Coast, the East Coast, the North Municipalities and the North Coast, plus Liaoning province from Northeast China and Guangxi province from Southwest China. The Central region contains Central China and Northeast China with the exception of Liaoning province. The Western region covers Southwest China and Northwest China with the exception of Guangxi province.

Table 4.1: The Regional Classification of Multi-Regional I-O tables

Region		Provinces
NE	Northeast China	Liaoning, Jilin, Heilongjiang
NM	North Municipalities	Beijing, Tianjin
NC	North Coast	Hebei, Shandong
EC	East Coast	Shanghai, Jiangsu, Zhejiang
SC	South Coast	Guangdong, Fujian, Hainan
CC	Central China	Shanxi, Henan, Anhui, Hubei, Hunan, Jiangxi
NW	Northwest China	Shaanxi, Gansu, Ningxia, Qinghai, Xinjiang, Inner Mongolia
SW	Southwest China	Sichuan, Chongqing, Guizhou, Yunnan, Guangxi, Tibet

strategy was an apparent success for the Coast. But spillovers to other regions that were supposed to be part of "growth pole" phenomena were not as strong as hoped, so instead concern heightened regarding interregional income disparity.[2]

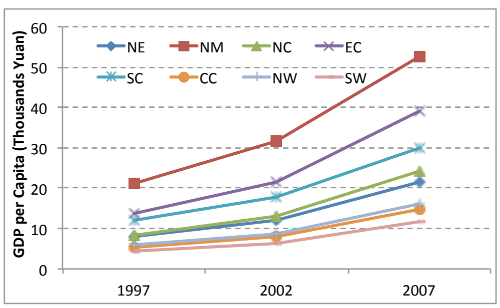


Figure 4.2: Regional per Capita GDP in China (in constant 2007 Yuan)

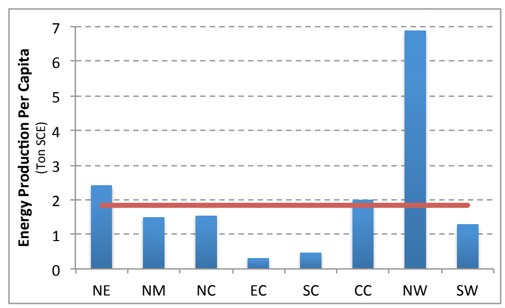


Figure 4.3: Primary Energy Production Level of Each Region in 2007

To alleviate regional inequality, Beijing launched the "Western Development Strategy" in 2000. It was designed to enhance capital investment, improve infrastructure, human capital, and technology in Northwest and Southwest China. In 2002, China's government adopted a strategy for the "Revitalization of Northeast China" to refuel the region's stagnant heavy-industry base by restructuring state-owned enterprises, introducing light manufacturing and service industries, and creating other new job opportunities. In 2004, the "Central China Rising" policy was adopted. It was designed to boost growth in China's bread basket, energy resource and equipment manufacturing

[2]From 1987 to 1997, GDP per capita grew 13.8% in the South Coast, 12.9% in the North Coast, and 11.8% in the East Coast annually, significantly higher than the national average level of 10.4%. Growth rates of Northern Municipalities (10.2%) and Southwest China (10.4%) were close to national average level while Northeast China (7.2%), Central China (9.5%), Northwest China (7.8%) had slower growth rates.

bases (see *Xinhua News* 2010; 2012, for details). From 1997 to 2007, these strategies at least seems to have resulted in a deceleration in the rise of disparity across China's regions. The average annual growth rates of GDP per capita in Northeast China, Central China, Northwest China and Southwest China were 10.4%, 10.7%, 10.7% and 10.3%, respectively, only slightly lower than the nation's annual average of 10.9%. However, the North Municipalities joined other coastal regions in its enjoyment of high rates of growth. In 2007, Northeast China (5.7%), Central China (6.2%), Northwest China (7.4%) and Southwest China (6.8%) had higher-than-average growth rates in construction (the nation's average was 5.4%). Hence, preferential policies offered by the central government seem to have boosted non-coastal economies through infrastructure investment.

A key factor of inequality across regions of China from 1997 to 2007 was their endowment of energy resources. Figure 4.4 shows that Northwest China had the largest energy production per capita in 2007.[3] The East Coast and South Coast were energy sinks. Raw coal resources were concentrated in Northwest and Central China (Li and Wei, 2010). In 2007, Inner Mongolia and Shaanxi province in the Northwest shipped more than half of their raw coal production to other provinces. Shanxi, in Central China, is a traditional coal-mining province. It accounted for 20.2% of the nation's coal production in 2009. Coal was transported from Northwest and Central China to the coast. The Northeast ranked second in energy production in 2007 because of its wealth in oil and natural gas resources. In 2007, Heilongjiang province in Northeast China accounted for 36.4% of the nation's total crude oil production. With the implementation of the "West Development Strategy," Xinjiang province in Northwest China became one of the largest oil-producing and -processing areas of China. Sichuan province in Southwest China and Xinjiang province in Northwest China are now China's largest natural gas bases.

Energy consumption in China is also unequal (shown in *Figure* 4.4). In 2007, the North Municipalities used 4.1 tons SCE per person, about 250% of the consumption in

[3]Energy production of each region includes two parts: indigenous production and recovery of energy.

Southwest China. Energy use per person in the North Municipalities, the North Coast, Northeast China, the East Coast, and Northwest China was significantly higher than in the South Coast, Central China, and Southwest China. All regions experienced a significant jump in energy consumption from 1997 to 2007. The growth rate in the North Coast was the highest.

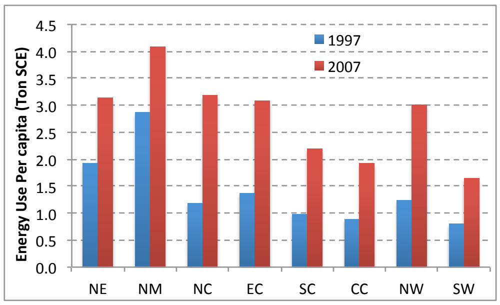


Figure 4.4: Per Person Energy Use of Each Region in China

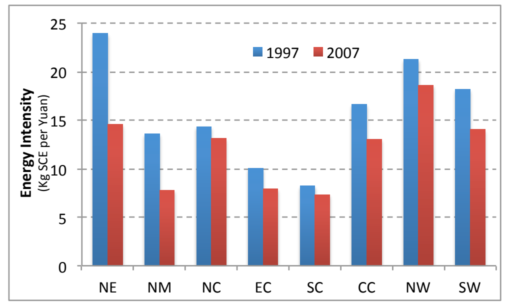


Figure 4.5: Regional Energy Intensity in China

Energy intensity (energy consumption per GDP) is an official combined indicator of local economic performance and energy conservation policies in China. In the 11^{th} FYP, China sought to reduce energy intensity by 20% from the 2005 level. In the end, a 19.1% reduction was achieved (Tsinghua University Climate Policy Initiative, 2012). In the 12^{th} FYP, China sought to reduce energy intensity by 16% by 2015 from its 2010 level. The National Development and Reform Commission (2011) detailed the national target to the provincial level into five categories.[4] In the 12^{th} FYP, coastal regions have higher energy reduction targets. Other regions, especially Northwest China, have lower targets. The targets do not reflect actual regional energy intensity patterns in China.

As shown in *Figure* 4.5, South China always had the lowest energy intensity from 1997 to 2007. Northeast China had the highest energy intensity in 1997. It was displaced by Northwest China in 2007. From 1997 to 2007, the overall energy intensity of China decreased 22.8% from 14.9 kg SCE per Yuan to 11.5 kg SCE per Yuan (constant 2007 price). Northeast China and the North Municipalities contributed most to the reduction

[4]Five categories: 1: 18% reduction: Tianjing, Shanghai, Jiangsu, Zhejiang, Guangdong; 2: 17% reduction: Beijing, Hebei, Liaoning, Shandong; 3: 16% reduction: Shanxi, Jilin, Heilongjiang, Anhui, Fujian, Jiangxi, Henan, Hunan, Hubei, Chongqing, Sichuan, Shaanxi; 4: 15% reduction: Inner Mongolia, Guangxi, Guizhou,Yunan, Gansu, Ningxia; 5: 10% reduction: Hainan, Tibet, Qinghai, Xinjiang.

in energy intensity. Energy intensity in these two regions decreased 39.0% and 42.7% correspondently. As the heavy industrial base, the Northeast China experienced rapid industrial restructuring and efficiency improvement in production processes during this decade. The decline of energy intensity in the North Municipalities was likely caused by the Chinese government's effort to phase out energy intensive industries in this region to prepare for the 2008 Beijing Olympic Game (Xinhua News, 2007). In 2007, only the East Coast, the South Coast, and the North Municipalities had lower than average energy intensity. Low energy intensities and slow reduction rates along the coast suggest it is unlikely that coastal regions will be able to achieve the high energy reduction targets set for them by Beijing. The higher energy intensities of central and western regions, especially Northwest China, suggest that these regions are more likely to achieve their energy intensity targets. Clearly, the unequal distribution of energy resources and their consumption will continue to play a role in regional inequality.

4.2.3 Population Migration

After the implementation of the "One Child Policy" in the 1980s, the population growth rate in China slowed. China's total population increased at an average annual rate of just 0.6% from 1,233 million in 1997 to 1,299 million in 2007. None the less, the North Municipalities and the South Coast enjoyed a 2.3% average annual population growth rate during these 10 years. Also, the populations of the East Coast and Northwest China grew 1.1% and 0.8% annually (see *Figure* 4.8). During this decade, the population in coastal China rose faster than other regions. As shown in *Figure* 4.6, inter-provincial migrants accounted for over 10% of the total population in the North Municipalities, the East Coast, and the South Coast in 2005.[5] From 2000 to 2005, the total inter-provincial migrant population increased 7.77 million in China. The East Coast, South Coast, and North Municipalities accounted for 74%, 25%, and 18% of the increment respectively. The population of inter-provincial migrants in Central China, Northwest

[5] Floating migrants are people who leave home to search for better financial rewards or opportunities. They may go to a nearby town or even thousands miles way across China. Inter-provincial migrants refers to those who went to a different province to seek for better job opportunities or rewards.

China, and Southwest China declined during these five years. In all, there is a trend of people migrating from the central and western parts of China to the coastal area for better job opportunities (Yang and Lahr, 2008).

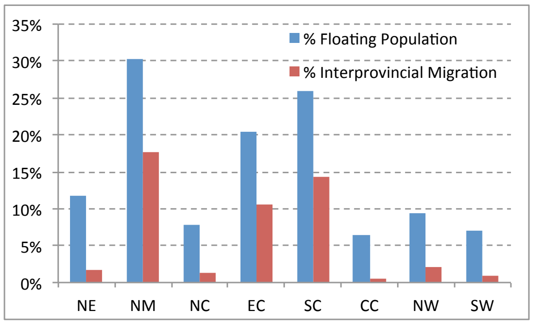


Figure 4.6: Share of Floating and Inter-provincial Migration to Total Population in 2005 (Taylor, 2011)

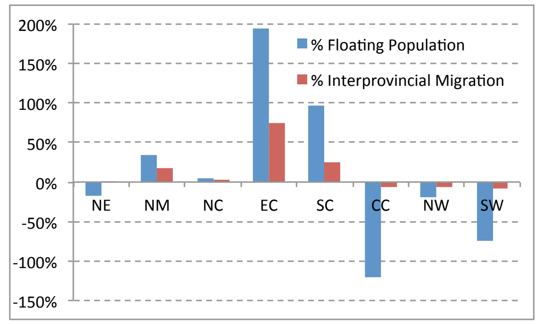


Figure 4.7: Regional Share in Changes of Floating and Inter-provincial Migration from 2000 to 2005 (Taylor, 2011)

In part due to inter-provincial migration, China has experienced rapid urbanization since 1980s. The share of population living in urban China rose from 19.4% in 1980 to 49.9% in 2010. The urbanization rate varied across regions in China. The North Municipalities had the highest urbanization level. In 2007, over 80% of its population lived in cities. The urbanization in the East Coast (59.1%), the South Coast (58.9%), and Northeast China (55.8%) were also much higher than the national average level (45.8%). The North Coast, Central China, and both Northwest and Southwest China had lower-than-average urbanization levels. In Southwest China, only 35.2% of people lived in urban areas in 2007. The urbanization levels of coastal areas (except the North Coast) and Northeast China are much higher than in central and western China.

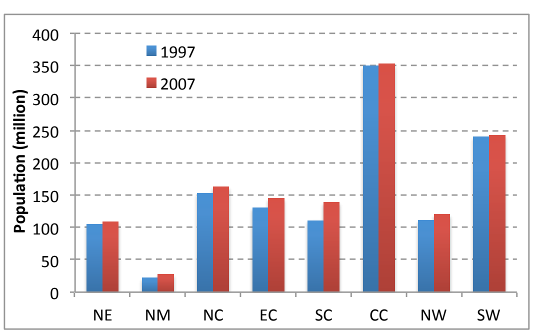


Figure 4.8: Regional Population Trend in China, 1997-2007

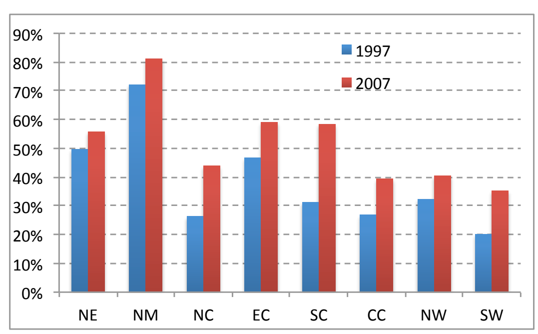


Figure 4.9: Share of Urban Population in Each Region

4.3 Methodology and Data

As in Chapter 3, $E = \mathbf{e}'(\mathbf{I}-\mathbf{A})^{-1}\mathbf{y} = \mathbf{e}'\mathbf{L}\mathbf{y}$ is used to calculate household indirect energy use of each region for a particular time point. A multiplicative framework is adopted to decompose changes in household indirect energy use into its determinants.

E: aggregated household indirect energy consumption (scalar);

$\mathbf{e}'$: vector with e_i^j as energy input per unit of output of industry i in region j ($NR\times 1$ vector);

$\mathbf{I}$: identity matrix ($NR\times NR$ matrix);

$\mathbf{L}$: Leontif-inverse matrix: a matrix of total input requirements ($NR\times NR$ matrix), $\mathbf{L} \equiv (\mathbf{I}-\mathbf{A})^{-1}$;

$\mathbf{y}$: vector of household final demand by region s ($NR\times 1$ vector). Element y_i^{js} denotes households' final demand for commodity i produced in region j, by region s. Since population of each region changes over years, household spending of region s ($\mathbf{y}$) can be decomposed into per capita urban and rural household spending $\mathbf{Hp}$ ($NR\times 2$ matrix) and rural and urban population $\mathbf{p}$ (2×1 vector) with $\mathbf{y} = \mathbf{Hp} * \mathbf{p}$.

To capture total population change and the effect of urbanization, $\mathbf{p}$ is further decomposed into $\mathbf{p} = \mathbf{u}\circ\tau$.[6] $\mathbf{u}$ indicates the shares of urban and rural population of total population in region s (2×1 matrix) and τ shows the total population in region s (scalar). Also $\mathbf{Hp}$ is decomposed into structure and volume components with $\mathbf{Hp} = \mathbf{Hs} * \mathbf{Hv}$. $\mathbf{Hs}$ shows the structure of household spending. Each cell is derived as the ratio of the corresponding cell in the $\mathbf{Hp}$ matrix to its column sum ($NR\times 2$ matrix); $\mathbf{Hv}$ is the aggregation of household spending per capita for urban and rural households in region m (2×1 vector).

Thus, letting $E = \mathbf{e}'(\mathbf{I}-\mathbf{A})^{-1}\mathbf{y} = \mathbf{e}'\mathbf{L}(\mathbf{Hp} * \mathbf{p}) = \mathbf{e}'\mathbf{L}((\mathbf{Hs} * \mathbf{Hv}) * (\mathbf{u}\circ\tau))$. Based on Dietzenbacher et al. (2000), we decompose $\mathbf{A}$ and $\mathbf{Hs}$ further to show the effects of changing interregional trade. The Leontief inverse can be written as $\mathbf{L} = (\mathbf{I}-\mathbf{A})^{-1} = (\mathbf{I}-\mathbf{A}^*\circ\mathbf{T}^{\mathbf{A}})^{-1}$ and per capita household spending can be written as $\mathbf{Hp} = \mathbf{Hs} * \mathbf{Hv} = (\mathbf{Hs}^*\circ\mathbf{T}^H) * \mathbf{Hv}$.

---

[6] Here, $\circ$ denotes Hadamard product (element-by-element multiplication of matrices).

$\mathbf{A}^*$: the matrix constructed by stacking R identical $N \times NR$ matrices of aggregate intermediate inputs per unit of gross output by industry by region ($NR \times NR$ matrix), $\forall j : [a^*] = \sum_{j=1}^{R} a_{ik}^{js}$;

$\mathbf{T^A}$: the set of intermediate trade coefficients that show the input shares of each region in aggregated inputs by industry by region ($NR \times NR$ matrix). $[t^A]_{ik}^{js} = a_{ik}^{js}/[a^*]_{ik}^{js}$, note that $\sum_j [t^A]_{ik}^{js} = 1$;

$\mathbf{Hs}^*$: the matrix constructed by stacking R identical $N \times 2$ matrices of household spending for product i by region j [$NR \times 2$ matrix], $\forall j : [Hs^*] = \sum_{j=1}^{R} Hs_{ik}^{j}$;

$\mathbf{T^H}$: the set of final demand trade coefficients that indicate the shares of region j in aggregated household spending for product i in region s [$NR \times 2$ matrix]. $[t^H]_i^{js} = Hs_i^j/[Hs^*]_i^j$, note that $\sum_j [t^H]_i^j = 1$;

The final decomposition of household indirect energy use change of region s can then be written as:[7]

$$
\begin{aligned}
\frac{E_1}{E_0} &= (4.1a) \times (4.1b) \times (4.1c) \times (4.1d) \times (4.1e) \times (4.1f) \times (4.1g) \times (4.1h) \\
&= \frac{\mathbf{e'}_1\mathbf{L}_1\mathbf{y}_1}{\mathbf{e'}_0\mathbf{L}_1\mathbf{y}_1} && \text{(4.1a)} \\
&\times \frac{\mathbf{e'}_0(\mathbf{I} - \mathbf{A}_1^* \circ \mathbf{T}_1^A)^{-1}\mathbf{y}_1}{\mathbf{e'}_0(\mathbf{I} - \mathbf{A}_0^* \circ \mathbf{T}_1^A)^{-1}\mathbf{y}_1} && \text{(4.1b)} \\
&\times \frac{\mathbf{e'}_0(\mathbf{I} - \mathbf{A}_0^* \circ \mathbf{T}_1^A)^{-1}\mathbf{y}_1}{\mathbf{e'}_0(\mathbf{I} - \mathbf{A}_0^* \circ \mathbf{T}_0^A)^{-1}\mathbf{y}_1} && \text{(4.1c)} \\
&\times \frac{\mathbf{e'}_0\mathbf{L}_0[((\mathbf{Hs}_1^* \circ \mathbf{T}_1^H) \times \mathbf{Hv}_1) \times \mathbf{p}_1]}{\mathbf{e'}_0\mathbf{L}_0[((\mathbf{Hs}_0^* \circ \mathbf{T}_1^H) \times \mathbf{Hv}_1) \times \mathbf{p}_1]} && \text{(4.1d)} \\
&\times \frac{\mathbf{e'}_0\mathbf{L}_0[((\mathbf{Hs}_0^* \circ \mathbf{T}_1^H) \times \mathbf{Hv}_1) \times \mathbf{p}_1]}{\mathbf{e'}_0\mathbf{L}_0[((\mathbf{Hs}_0^* \circ \mathbf{T}_0^H) \times \mathbf{Hv}_1) \times \mathbf{p}_1]} && \text{(4.1e)} \\
&\times \frac{\mathbf{e'}_0\mathbf{L}_0[((\mathbf{Hs}_0^* \circ \mathbf{T}_0^H) \times \mathbf{Hv}_1) \times \mathbf{p}_1]}{\mathbf{e'}_0\mathbf{L}_0[((\mathbf{Hs}_0^* \circ \mathbf{T}_0^H) \times \mathbf{Hv}_0) \times \mathbf{p}_1]} && \text{(4.1f)} \\
&\times \frac{\mathbf{e'}_0\mathbf{L}_0[\mathbf{Hp}_0 \times (\mathbf{u}_1 \circ \tau_1)]}{\mathbf{e'}_0\mathbf{L}_0[\mathbf{Hp}_0 \times (\mathbf{u}_0 \circ \tau_1)]} && \text{(4.1g)} \\
&\times \frac{\mathbf{e'}_0\mathbf{L}_0[\mathbf{Hp}_0 \times (\mathbf{u}_0 \circ \tau_1)]}{\mathbf{e'}_0\mathbf{L}_0[\mathbf{Hp}_0 \times (\mathbf{u}_0 \circ \tau_0)]} && \text{(4.1h)}
\end{aligned}
$$

Household indirect energy consumption change is decomposed into eight partial

[7]Here I show only one side of the polar decomposition. In the study, I examined both polar decompositions and use Fisher indexes to analyze result. Fisher indexes are obtained by taking the geometric average of corresponding elements of the polar decompositions (Dietzenbacher et al., 2000).

effects:

$\Delta\mathbf{e}'$: effect of changes in energy requirements per unit of output (Eq: 4.1a);

$\Delta\mathbf{A}^*$: effect of changes in inter-industrial production structure (Eq: 4.1b);

$\Delta\mathbf{T}^{\mathbf{A}}$: productivity effect of changed regional trade structures of intermediate inputs (Eq: 4.1c);

$\Delta\mathbf{Hs}^*$: effect of changes in household consumption structure (Eq: 4.1d);

$\Delta\mathbf{T}^{\mathbf{H}}$: effect of changes in interregional trade structure of commodities and services consumed by households in region s (Eq: 4.1e);

$\Delta\mathbf{Hv}$: effect of changes in per capita household consumption level in region s (Eq: 4.1f);

$\Delta\mathbf{u}$: effect of changes in the share of urban population of total population in region s (Eq: 4.1g);

$\Delta\tau$: effect of changes in total population in region s (Eq: 4.1h).

Multiregional input-output (MRIO) tables provide regional information as well as estimates of interregional trade. They do so by capturing the structure of production of a specific region (A_{jj}) as well as net interregional flows (A_{js}). The MRIO tables used in this chapter are for the years 1997 and 2007. These tables were compiled by the China State Information Center and include 17 sectors and 8 regions (China State Information Center, 2005; Zhang and Qi, 2012). Since all MRIO tables used here were published in current prices, RAS is used to adjust them into 2007 prices (Dietzenbacher and Hoen, 1998). As suggested by Yang and Lahr (2008), I used the agricultural producer price index for the primary industry and free-on-board price index for the secondary industry to adjust prices. For the tertiary and construction industries, a set of implicit GDP price indexes was used.[8]

Data on household direct energy use is compiled using provincial data from the *China Energy Databook* (Lawrence Berkeley National Laboratory, 2008). For household indirect energy use, regional energy consumption data is aggregated from *Provincial Energy Balance Tables* in China Energy Statistical Yearbooks (NBS, 1990; 2001; 2004;

[8] Implicit GDP: dividing nominal GDP by real GDP of these industries.

2008). Since *Provincial Energy Balance Tables* report only production-related energy consumption for 6 sectors, I use national energy consumption data by industry to map regional energy use to 17 sectors. All other demographic and GDP data are from the *China Statistical Year Book*.

4.4 Residential Direct Energy Use

Residential direct energy use per capita varied across regions (see *Figure* 4.10). On average, China's households consumed 211 kg SCE energy per capita directly in 2005. Residents in the North Municipalities (NM) consumed 519 kg SCE energy per capita, much higher than other regions. Only *Central China* (CC) and *Southwest China* (SW) consumed less energy directly compared to the national average. They are two of the the three poorest regions of China. The third, Northwest China, consumes 25% more than the national average due to extreme climatic conditions there. So it appears that relative wealth and climate play key roles in direct residential energy consumption.

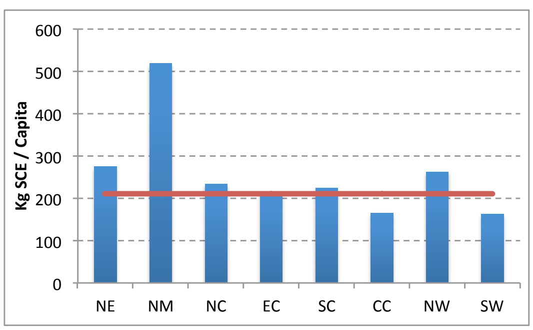


Figure 4.10: Per capita direct residential energy consumption by region. 2005

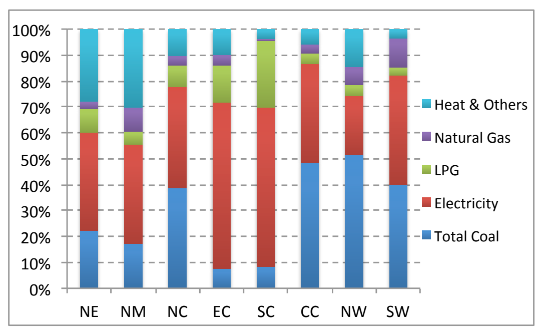


Figure 4.11: Share of fuel type of residential energy use in each region, 2005

The fuel mix of direct residential energy use also varied across regions. In 2005, coal was still a major energy source for households in the North Coast (39%), Central China (48%), Northwest (51%), and Southwest China (40%). Electricity played a more important role in households' lives in the East Coast and the South Coast, accounting for over 60% of residential direct energy use there. However, it only accounted for 23% of total direct energy use for residents in Northwest China. LPG was an important component of households' daily energy use in the East Coast (14%) and the South

Coast (26%). The share of natural gas in direct residential energy use was low in all regions in 2005. Its share was higher in Northwest and Southwest China where China's natural gas bases are located. With the start of "Transmit Natural Gas from Western Areas to East China Project" since 2005, residents in coastal areas began to use natural gas in their homes. As a result, natural gas will play a more important role in Chinese households' lives.

4.4.1 Climate Zone and Thermal Comfort

As hinted at earlier, residential direct energy use depends highly on climate. China's Ministry of Construction divides China into five climate zones for thermal design of civil buildings (see *Figure* 4.12 and *Table* 4.2). *Table* 5.1 tries to match the regional classification of this dissertation with climate zones. Most of Northeast China (NE) is located in the *Severe Cold Zone*; most of the North Municipalities (NM), the North Coast (NC), and Northwest China (NW) are located in the *Cold Zone*; most of the East Coast (EC) is located in the *Hot Summer, Cold Winter Zone*; and most of the South Coast (SC) is located in the *Hot Summer, Warm Winter Zone*. Central China (CC) and Southwest China (SW) are located across several climate zones (see *Table* 5.1).

Table 4.2: Climate Zones in China

Climate Zone	Climate Characteristics	
	Mean Month Temp	HND & CND
Severe Cold Zone	Coldest Month: ≤ -10°C (14°F)	HND $\geq$ 145 Days
Cold Zone	Coldest Month: -10∼0°C (14∼32°F)	HND: 90∼145 Days
Hot Summer Cold Winter Zone	Coldest Month: 0∼10°C (32∼50°F) Hottest Month: 25∼30°C (77∼86°F)	HND: 0∼90 Days CND: 40∼110 Days
Hot Summer Warm Winter Zone	Coldest Month>10°C (50°F) Hottest Month: 25∼29°C (77∼84°F)	CND: 100∼200 Days
Temperate Zone	Coldest Month: 0∼13°C (32∼55°F) Hottest Month: 18∼25°C (64∼77°F)	CND: 0∼90 Days

Note: HND: days that need heating, with average daily temperature $\leq$ 5°C (41°F); CND: days that need cooling, with average daily temperature $\geq$ 25°C (77°F);
Source: Thermal Design Code for Civil Building (Ministry of Construction, 1994b)

Climate differences affect household direct energy use largely through heating and cooling requirements. The northern part of China is mainly located in the *Severe Cold*

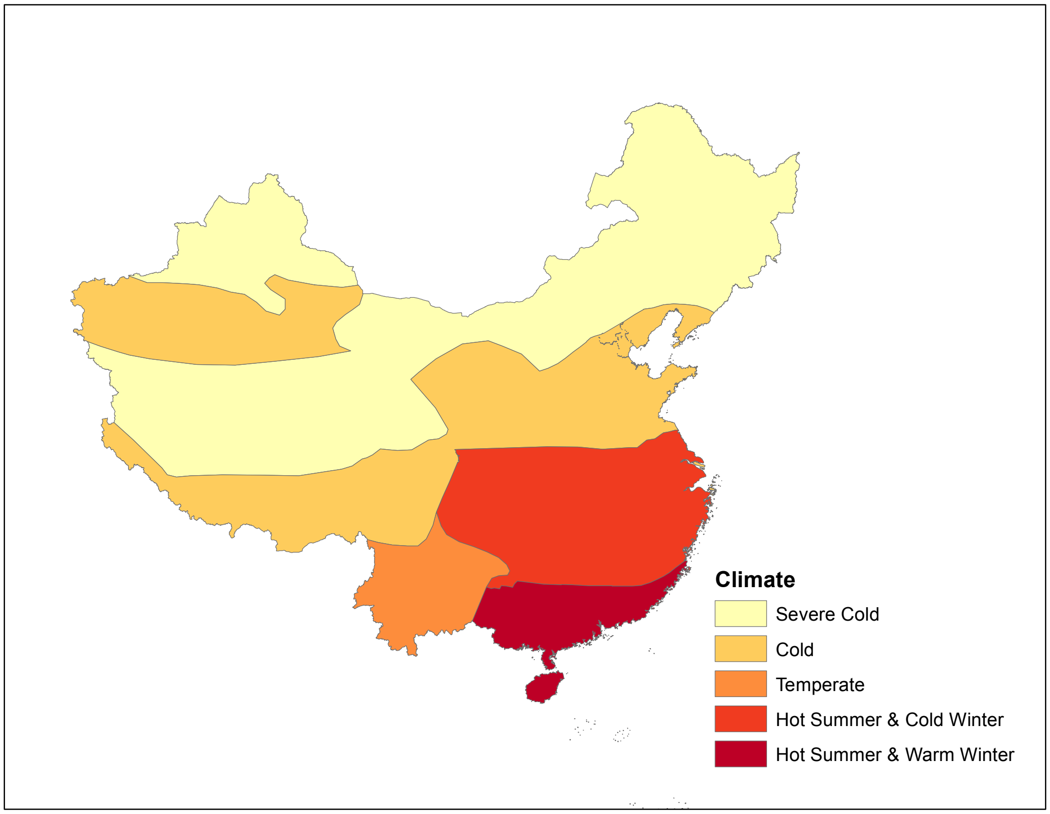


Figure 4.12: China Climate Zones

Zone and the *Cold Zone*, where demand for heating is high. Urban households in Northeast China (NE), the North Municipalities (NM), the North Coast (NC), and both Shanxi, and Henan provinces in Central China (CC) have access to central heating.[9] Yoshino et al. (2006) indicate that the average room temperatures of major cities in heating zones range around 18–20°C in the winter. In these cities, temperature differences between living space and bedrooms are very small. For cities without access to central heating, the average room temperatures typically range around 10–17°C. In these cities, bedroom temperatures are kept higher than are temperatures in living space. For most cities with access to central heating, indoor temperature falls into the ASHRAE comfort zone[10] in winter. For cities without central heating, indoor

[9]Central heating refers to heating from public heating supply system. Heating is generated by state-owned heating supply enterprises and distributed to commercial and residential buildings through piped networks.

[10]ASHRAE Standard 55 (Thermal Environmental Conditions for Human Occupancy) is an standard to evaluate human occupants' satisfaction with the thermal environment. It is published by *American Society of Heating, Refrigerating and Air Conditioning Engineers.*)

temperature is far from the ASHRAE comfort zone. During hot summers, Chinese households typically cool their homes by opening windows, using electric fans, and turning on air-conditioning systems. With income increases and lifestyles changes in China, households' demand for thermal comfort is rising.

4.4.2 Space Heating and Cooling

As shown in *figure* 4.10, residents in the northern part of China consume more energy than do their counterparts in other regions. Residents of cities with access to central heating enjoyed higher thermal comfort during cold winters (Yoshino et al., 2006). In the Heating Zone, space with access to central heating has increased rapidly during the past decade. This rising trend is likely to continue (Yao et al., 2005). For regions located in the *Hot Summer, Cold Winter Zone*, central heating is not yet generally available. With increasing income, residents' ways of warming their homes has gradually moved from adding more blankets, wearing more clothes, and sleeping with hot water bottles to using a heater and to adding a heat pump. Rising heating demand in the *Hot Summer, Cold Winter Zone* will draw up electricity usage in the East Coast and Central China. Zhang (2004) expects that demand for heating in China will continue to rise at an average annual rate of 1.7%, even after 2030 when China's total population is expected to decrease. He further notes that most of the growth should occur before 2040.

Compared to heating, space cooling is a relatively less important energy use in many developing countries. However, its use is growing quite rapidly in China (Isaac and Van Vuuren, 2009). Due to climate differences, cooling demand is high in the South Coast, the East Coast, and Central China. Energy consumption for cooling is highly related to appliance ownership. Here, families' ownership of air conditioners proxies for energy used for cooling in each region. *Figure* 4.13(d) shows the regional disparities in the ownership of air conditioners. Households ownership of air conditioners in Northeast and Southwest China was low in 2007. Since these two regions have fairly cool summers, their demand for cooling is quite low. In urban areas of the South Coast, the East Coast, and the North Municipalities, the ownership of air conditioners is almost saturated. On average, every urban household in these regions owns over 1.6 air conditioning units, about twice the ownership rate in urban areas of the North Coast, Central China, and Southwest China. Also, the disparity of air-conditioner ownership between urban and rural areas is rising. In the South Coast, urban households own over 1.7 units on average, while their rural counterparts own just 0.2 units. On average, rural households in the North Municipalities and the East Coast owned about 0.6 air conditioners. The ownership of air conditioners is very low in rural areas of other regions. Regional disparities in air conditioner ownership suggest that space-cooling demand is affected by both the prevailing climate and households' income level. Generally and not surprisingly, demand for cooling in northern China is lower than in the southern part. Households in the relatively developed North Municipalities have much higher ownership rates than do households in the North Coast, even through these two regions have similar climates. With increased income, cooling demand is expected to rise in the urban areas of Central China and the North Coast as well as nearly all rural areas in China outside of Northeast and Northwest China.

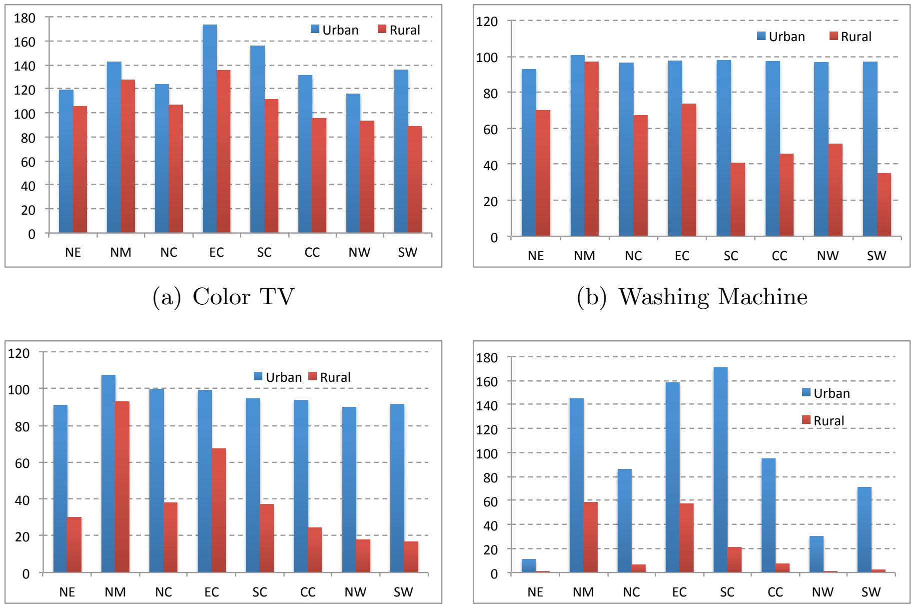
With increased demand for indoor thermal comfort, Chinese households' demands for heating and cooling are expected to rise rapidly. This will greatly increase household direct energy use in winter and summer. Heating demand should increase rapidly in the *Hot Summer, Cold Winter Zone*. Without central heating, heating demand in these regions will cause a winter surge in electricity usage through the use of electric heaters and heat pumps. Recently, some households have adopted natural-gas fired boilers to generate heat in their homes. In all, increasing heating demand will in turn increase the demand for coal to generate heat in the heating zone, and will increase the demand for electricity and natural gas to generate heat in non-heating zones. Due to the increasing demand for cooling in rural China as well as urban areas in Central China and the North Coast, electricity usage during summers is also expected to increase. Local governments face an urgent question of how to meet the rising electricity demand and prevent and alleviate electricity "summer peaks" in these regions.

4.4.3 Electric Home Appliances Usage

Possession of electric appliances reflects a household's lifestyle. Home appliances either enable time-savings or meet households' increased sanitation or comfort demand (Genjo et al., 2005). Increasing ownership of electric home appliances contributes substantially to the growth of residential energy consumption. As shown in *Figure* 4.13, home appliances like color TVs, washing machines, and refrigerators had already penetrated urban households' lives in all regions by 2007. Almost every urban household owns a washing machine, a refrigerator, and more than one color TV. For urban households in relatively undeveloped Central China, Northwest China, and Southwest China, the ownership of color TVs and refrigerators is less than one per household. Although ownership of home appliances seems saturated in urban China, it remains lower than in developed countries. In Japan, in 2000 households owned 1.2 refrigerators and 2.2 air conditioners on average (Zhou et al., 2009). If Chinese households converge toward a Japanese lifestyle, the demand of refrigerators and air conditioners in urban China looms high.

Home appliance ownership by rural households varied widely across regions. In rural areas, washing-machine, refrigerator, and air-conditioner ownership was higher in the North Municipalities and the East Coast. In fact, statistics suggest that every rural household owned a washing machine and a refrigerator in the North Municipalities in 2007. Rural households owned more than one color TV per household in all regions except in relatively less-developed Central China, Northwest China, and Southwest China. For these three regions, rural households' ownership of washing machines and refrigerators was also lower than in other regions. Disparities in rural households' ownerships of home appliances across regions correlated well with disparities in regional per capita GDP as shown in *Figure* 4.2. So it seems that the demand for home appliances in rural areas, especially in central and western parts of China, is positioned to rise rapidly.

Energy used by home appliances is not only determined by home appliance ownership but also by the energy efficiency of them (Zhou et al., 2009). China's government



(a) Color TV

(b) Washing Machine

(c) Refrigerator

(d) Air Conditioner

Figure 4.13: Average Home Appliances Ownership per 100 Families in 2007

adopts "*minimum energy performance standards (MEPS)*" and "*voluntary laveling system*" for home appliances to promote the use of energy-efficient products (Zhou, 2008). MEPS and labeling programs have been updated and revised to reflect technological improvements of these products. Fridley et al. (2007) indicate that China's current appliance energy efficiency standard and labeling programs should save 1143 TWh of energy from 2000 to 2020, about 9% of total residential electricity usage during these two decades. However, monitoring and enforcement of these energy efficiency standards and labels are both grossly under-funded in China (Zhou, 2008). The energy efficiency performance of available home appliances is mainly reported by producers. Government's monitoring of "truth in advertising" is lax. Also, current standards in China are far less stringent than are standards adopted in developed countries like the Germany and Japan (Fridley et al., 2007). As the world's largest home appliance producer, China has abilities to produce high energy-efficient home appliances tailored to its domestic market. With this domestic demand in mind, China should develop new and adopt tight standards and labeling criteria to help its domestic users to catch up with international best practices. Government also should monitor and enforce its standards to improve home appliances energy efficiency. Since China's appliance stock is expected to grow rapidly, aggressive energy efficiency standards could be adopted to help curb the surge in energy demand that is likely to emerge from expanded use of home appliances by China's domestic market.

4.5 Residential Indirect Energy Use

The energy embodied in household consumption varied widely across regions and even between rural and urban areas in the same region. In 2007, indirect energy consumption of urban households varied from 1133 kg SCE per person in East Coast to 708 kg SCE per person in Southwest China. Urban residents in Southwest and Northwest China consumed only 708 kg SCE and 720 Kg SCE per capita, respectively, about 20% less than average level of urban China more generally. Regional disparities in urban households' indirect energy use are likely caused by the disparities in household income across regions. This similar pattern can also be found in the indirect energy use by rural households. Rural households in the East China consumed more energy indirectly than they did in other rural regions. Rural households in less developed Northwest China and Southwest China consumed just 68% and 72% of the average rural household indirect energy consumption level (See Figure 4.14).

The gap in per capita household indirect energy use between urban and rural residents is even larger than inter-regional disparities. In 1997, per capita indirect energy use of a typical urban resident was 2.5 times that of a typical rural resident. This ratio increased to 3.6 by 2007. From 1997 to 2007, the gap in per capita indirect energy consumption between urban and rural residents grew in all regions except in Northeast China. In 2007, this urban-to-rural ratio varied from 2.4 in East China to 4.3 in Northwest China. With rapid urbanization, rural residents migrated to urban areas. In doing so, they gradually adopted urban lifestyles with high ownership of electric appliances and the consumption of processed food. Thus, urbanization is likely to continue to be an important determinant of the growth in energy use.

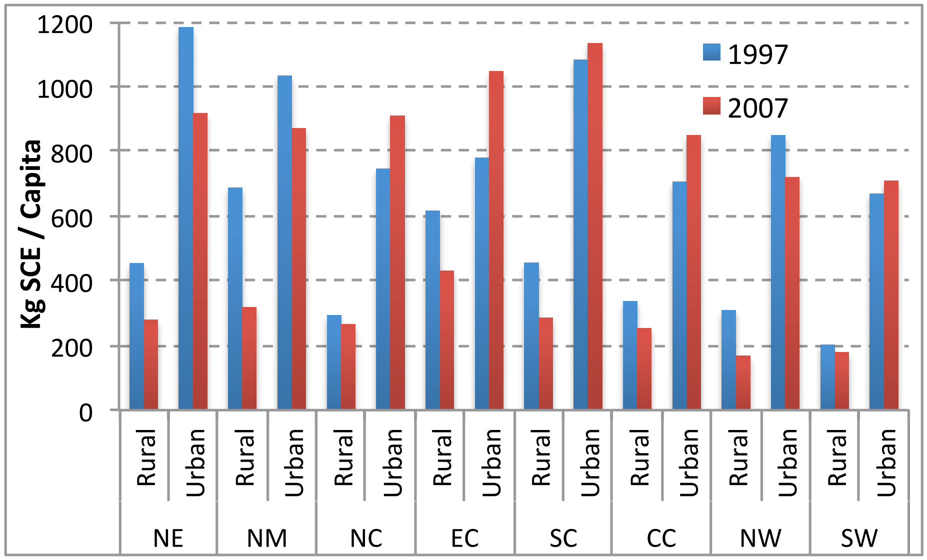


Figure 4.14: Per Capita Household Indirect Energy Use in China

From 1997 to 2007, the average amount of embodied energy consumed by urban households in China increased 6.8% from 844 kg SCE per person to 901 kg SCE, while the average embodied energy consumed by rural household *decreased* 27.0% from 341 kg SCE per person to 249 kg SCE (See *Figure* 4.14 and *Table* 4.4). The decline in embodied energy use in rural areas is mainly caused by the energy efficiency gains in production processes. However, urban households in the East Coast, the North Coast, Central China, Southwest China, and the South Coast enjoyed 34%, 22%, 20%, 6%, and 5% rises in per capita embodied energy consumption from 1997 to 2007 despite significant efficiency gains in the production process. In these locales, rapidly rising urban household demand overrode energy efficiency gains.

4.5.1 The Contributions of Different Drivers to Household Indirect Energy Use

From 1997 to 2007, indirect energy use by households increased 16.7% from 610 Mtce to 712 Mtce. At the regional level, total household indirect energy use rose in most regions except in Northeast and Northwest China. But household indirect energy use actually declined 19.7% and 12.5% in Northeast and Northwest China, respectively. The South Coast (50.2%), North Coast (41.9%), East Coast (28%) and Southwest China (24.6%)

all enjoyed above average rises in household indirect energy use. However, the rises in Central China and the North Municipalities were slower than the national average level. This section examines the aspect of household consumption that may affect energy demand such as changes in the household consumption baskets, changes in the level of consumption per capita, changes in urbanization, and population changes.

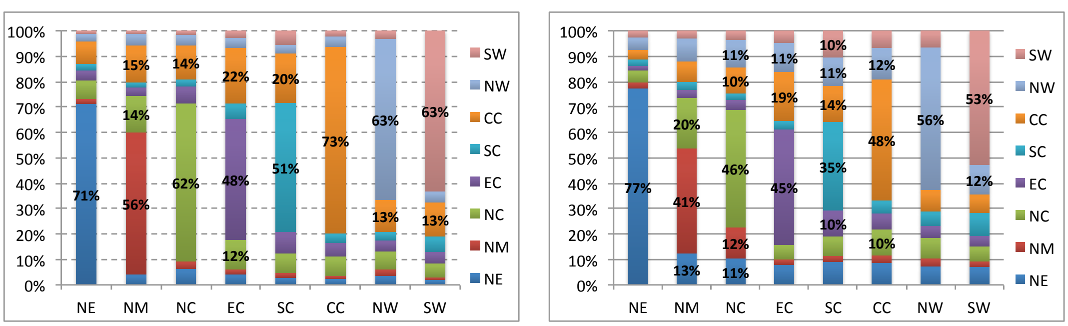
From 1997 to 2007, changes in household consumption ($\Delta\mathbf{Hv}$) contributed most to the rises in household indirect energy use in all regions. It drove up household indirect energy use by 82% in the East Coast and by 73% in the North Coast. Changes in production energy efficiency ($\Delta\mathbf{e}'$) offset the effect of rising household consumption levels in most regions except the North Coast, the East Coast, and Southwest China. The changing structure of intermediate inputs ($\Delta\mathbf{A}^*$) also dampened the effect of rising household energy use in all regions except the North Coast. Changes within the household consumption basket ($\Delta\mathbf{Hs}^*$) helped dampen indirect energy use by about 15% in the North Municipalities and the North Coast. That is, households in these regions adopted more energy efficient purchase patterns. However, it enhanced indirect energy use by 11% in the South Coast. Households in the South Coast consumed higher share of energy through *metal products* and *transportation and trade.*

Population migration increased household indirect energy use in all regions from 1997 to 2007. This is because migration was largely rural to urban and as mentioned earlier urban lifestyles are more energy-intensive. Changes in urbanization levels ($\Delta\mathbf{u}$) significantly increased household indirect energy use in the South Coast (36%), Southwest China (26%), and the North Coast (25%). As shown in *Figure* 4.9, the share of urban population rose more quickly in these three regions than in other regions from 1997 to 2007. The share of people living in urban areas increased from 39% to 46% on average in China, but from 31% to 58% in the South Coast, from 26% to 44% in the North Coast and from 20% to 35% in Southwest China. Changes in total population increased household indirect energy use by 28% in the South Coast, 23% in the North Municipalities and 12% in the East Coast. As mentioned elsewhere, population has been migrating from central and western parts of China to coastal regions. From 1997 to 2007, the total population increased at an average annual rate of 2.3% and 1.1%

in the North Municipalities and the East Coast, respectively. Compared to effects of other factors, those from changes in the trade structure of intermediate inputs ($\Delta\mathbf{T}^{\mathbf{A}}$) and final goods and services ($\Delta\mathbf{T}^{\mathbf{H}}$) were trivial in all regions.

4.5.2 Role of Interregional Trade

In 1997, households in the East Coast, the South Coast, and the North Municipalities relied heavily on interregional trade to meet their indirect energy needs (see *Figure* 4.15(a)). As the main coal-producing region, Central China was a main source of indirect energy for other regions, contributing a significant share of indirect energy to other regions. The North Coast also contributed an important part of household indirect energy use for the nearby North Municipalities (14%) and the East Coast (12%). Most of the indirect energy is embodied in *mining and non-mineral products*, *metal products*, and *chemical products*. Central China also accounted for a significant share of household indirect energy use through its supply of *Electricity, gas and water supply* to other regions, especially to the North Municipalities (30%) and the East Coast (23%). Also, the North Coast contributed 24% of the energy for households through North Municipalities' demand for *Electricity, gas and water supply*.



(a) 1997 (b) 2007

Figure 4.15: Contribution of household indirect energy with respect of place of origin

From 1997 to 2007, all regions but Northeast China relied even more heavily on interregional trade of final goods and services to meet their household's indirect energy needs. Central China, Northwest China, and the North Coast played important roles in 2007 in providing indirect energy resources as embodied in goods and services delivered to households in other regions. Northwest China provided about 10% of energy indirectly used by households in the North Municipalities, the North Coast, the East Coast, the South Coast, Central China, and Southwest China. The North Coast contributed 20%, 10%, 8% and 8%, of households' indirect energy use in the North Municipalities, Central China, Northwest China, and the South Coast, respectively.

4.5.3 Changing Trend of Household Consumption Pattern

Table 4.7 shows the contributions of different sectors to changes in per capita household indirect energy use for each region from 1997 to 2007. Per capita household indirect energy use decreased in all rural regions, ranging from 27 kg SCE in the North Coast to 371 kg SCE in the North Municipalities. As mentioned above, most of these decreases were caused by energy efficiency gains in production processes and by changes to the structure of their input use. From 1997 to 2007, increased household consumption pushed up per capita household indirect energy use in rural areas. Compared to its rural counterparts, the level of consumption per urban household grew more quickly. The rapid rising final demand of China's urban households drove per capita household indirect energy use at average annual rates that ranged from 3.7% in Northwest China to 7.7% in the East Coast. The effects of rising total household consumption outpaced the effects of efficiency gains and of changes in the production input structure in all regions, except in Northeast China, the North Municipalities, and Northwest China.

In urban areas, strong growth in the use of services such as *Transportation and trade* and *Education, health and other services* accounted for much of the rise in household indirect energy use across all regions (see *Table* 4.7). Even in rural areas where per capita household indirect energy use decreased, per capita indirect energy use through *Transportation and Trade* grew. This was the case for the North Coast, the East Coast, the South Coast, and Central China. Also per capita indirect energy use through *Education, Health and Other Services* rose in Northeast China, the North Municipalities, the North Coast, the East Coast and Central China. This suggests that the rise in indirect energy use in China was caused by its adoption of lifestyles of developed countries.

Urban households in the East Coast, the South Coast, and Central China enjoyed a substantial rise in household indirect energy use through the use of *Metal Products* and *Chemicals Products*. *Chemical Products* also played an important role in increasing household indirect energy use in the North Coast. *Electricity and gas consumption* contributed significantly to the growth of per capita household indirect energy use in urban areas of the relatively less-developed North Coast, Central China, and Southwest China. This is not only due to the increased ownership and usage of electrical appliances, but also due to the increased electricity usage to produce goods and services (Feng et al., 2012). *Food product and processing* also played important roles in increasing energy use in all regions except the North Municipalities, the South Coast and Northwest China.

Table 4.3: Match of Climate Zone and Regional Classification

Region	Climate Zone
Northeast China (NE)	**Severe Cold Zone**: *Heilongjia*, *Jilin*; most of *Liaoning* **Cold Zone**: southern part of *Liaoning*
North Municipalities (NM)	**Cold Zone**: *Tianjing*; most of *Beijing* **Severe Cold Zone**: some northern part of *Beijing*
North Coast (NC)	**Cold Zone**: *Shandong*; most of *Hebei* **Severe Cold Zone**: some northern part of *Hebei*
East Coast (EC)	**Hot Summer Cold Winter Zone**: *Shanghai*, *Zhejiang*; most of *Jiangsu* **Cold Zone**: some northern part of *Jiangsu*
South Coast (SC)	**Hot Summer Warm Winter Zone**: *Hainan*; most of *Guangdong* and *Fujian* **Hot Summer Cold Winter Zone**: some northern part of *Guangdong* and *Fujian*
Central China (CC)	**Hot Summer Cold Winter Zone**: *Jiangxi*, *Hunan*, *Hubei*; most of *Anhui* and southern part of *Henan* **Cold Zone**: Most of *Shanxi*; northern part of *Henan* and some northern part of *Anhui* **Severe Cold Zone**: some northern part of *Shanxi*
Northwest China (NW)	**Cold Zone**: *Ningxia*, *Qinghai*; most of *Shaanxi*, *Xinjiang*, and *Gansu*; and western part of *Inner Mongolia* **Severe Cold Zone**: central and northern part of *Inner Mongolia*; some part of *Shaanxi* and *Xinjiang* **Hot Summer Cold Winter Zone**: some southern part of *Gansu*
Southwest China (SW)	**Temperate Zone**: most of *Yunnan*; southwest part of *Guizhou*, and *Sichuan* **Hot Summer Cold Winter Zone**: *Chongqing*; most of *Sichuan*; eastern part of *Guizhou*; northern part of *Guangxi* **Hot Summer Warm Winter Zone**: most of *Guangxi*; western part of *Yunnan* **Severe Cold Zone**: most of *Tibet* **Cold Zone**: some of *Tibet*

Source: Thermal Design Code for Civil Building GB 50176-93 (Ministry of Construction, 1994a)

Table 4.4: Per Capita Household Indirect Energy Use in China (Kg SCE)

Region	Rural			Urban		
	1997	2007	Total % Change	1997	2007	Total % Change
Northeast China (NE)	453	279	-4.7%	1183	918	-2.5%
North Municipalities (NM)	688	317	-7.4%	1034	871	-1.7%
North Coast (NC)	293	265	-1.0%	746	910	2.0%
East Coast (EC)	616	430	-3.5%	781	1047	3.0%
South Coast (SC)	456	285	-4.6%	1082	1133	0.5%
Central China (CC)	337	253	-2.8%	707	850	1.9%
Northwest China (NW)	309	169	-5.9%	849	720	-1.6%
Southwest China (SW)	202	179	-1.2%	669	708	0.6%
National Average	341	249	-3.1%	844	901	0.7%

Table 4.5: Household Indirect Energy Consumption of Different Regions (Mtce)

Region	1997			2007			Total % Change
	Rural	Urban	Total	Rural	Urban	Total	
NE	24.0	61.9	85.9	13.4	55.6	69.0	-19.7%
NM	4.2	16.4	20.6	1.6	19.4	21.1	2.5%
NC	33.0	30.1	63.1	24.3	65.3	89.5	41.9%
EC	42.8	47.5	90.3	25.6	90.0	115.6	28.0%
SC	34.8	37.4	72.1	16.4	91.9	108.3	50.2%
CC	86.4	66.4	152.7	54.0	118.3	172.3	12.8%
NW	23.3	30.6	53.8	12.1	35.0	47.1	-12.5%
SW	38.8	32.4	71.2	28.2	60.6	88.7	24.6%
Total	287.1	322.6	609.8	175.6	536.1	711.7	16.7%

Table 4.6: Driving Forces of Household Indrect Energy Use Change from 1997 to 2007

Region	$\Delta\mathbf{e}'$	$\Delta\mathbf{A}^*$	$\Delta\mathbf{T}^A$	$\Delta\mathbf{H}_s$	$\Delta\mathbf{T}^H$	$\Delta\mathbf{H}_v$	$\Delta\mathbf{u}$	$\Delta\tau$	Total
NE	-42%	-30%	1%	3%	0%	40%	5%	3%	-20%
NM	-63%	-4%	2%	-16%	0%	55%	5%	23%	2%
NC	-61%	6%	3%	-15%	4%	73%	25%	8%	42%
EC	-55%	-23%	3%	-3%	5%	82%	7%	12%	28%
SC	-66%	-28%	4%	11%	6%	61%	36%	28%	50%
CC	-58%	-13%	0%	1%	0%	68%	14%	1%	13%
NW	-46%	-11%	0%	2%	-3%	29%	10%	7%	-12%
SW	-47%	-12%	1%	4%	1%	51%	26%	1%	25%

Table 4.7: Key Sectors Contributing to per Capita Household Indirect Energy Use in Each Region, 1997-2007 (Kg SCE)

Sector	Urban								Rural							
	NE	NM	NC	EC	SC	CC	NW	SW	NE	NM	NC	EC	SC	CC	NW	SW
Food Production & Processing	15	-35	54	27	-35	17	-42	12	15	-50	0	-18	-33	-15	-24	-2
Textile & Wearing Apparel	-17	-9	-5	9	16	6	-9	8	-7	-9	-2	-3	1	-1	-5	3
Mining & Non-mineral Products	-136	-59	-34	-20	-34	-41	-70	-36	-62	-62	-21	-55	-35	-33	-30	-11
Metal Products	-99	-36	0	38	56	18	4	8	-51	-65	-10	-43	-19	-10	-8	-2
Chemicals	-24	-28	65	93	34	39	-28	5	-35	-87	0	-40	-43	-26	-37	-12
Electronic & Machinery Products	-14	-21	-13	-2	10	-6	-3	-7	-10	-27	-6	-13	-8	-4	-5	-1
Electricity, Gas & Water Supply	-21	-65	26	15	-45	38	1	21	-18	-52	-3	-19	-33	-1	-16	0
Transport & Trade	7	21	34	74	50	55	11	24	-7	-37	8	8	6	5	-6	1
Education, Health & Other Services	29	74	36	29	9	18	8	6	3	25	10	1	-3	5	-7	1
Others	-6	-4	1	3	-10	1	-2	-2	-4	-6	-1	-4	-5	-3	-3	-1
Total	-266	-163	164	266	51	144	-129	40	-174	-371	-27	-185	-171	-85	-140	-23

4.6 Conclusions and Outlooks

Household energy use varies across China's regions. In 2005, per capita direct energy use by households varied from 519 kg SCE in the North Municipalities to 162 kg SCE in Southwest China. Due to cold winters, residents in northern China consumed more energy directly than did their southern counterparts. Compared to energy that they used directly, households consumed even more energy indirectly as embodied in the goods and services they consume. Regional differences in energy embodied in household consumption are also large. In 2007, urban households in the East Coast consumed 1133 kg SCE energy per capita indirectly, while their counterparts in Southwest China consumed just 708 kg SCE per capita. Households in China's relatively developed coastal regions consumed more indirect energy than did households in its inland areas. The disparities in household indirect energy use between urban and rural residents within most regions are even larger. In Southwest China and the South Coast, rural residents consumed only 25% of what their urban counterparts consumed indirectly. Much of the differences expressed above is due to the relative self-sufficiency of rural households as well as the extreme wealth gap between urban and rural areas of China. Even in the East Coast, a rural resident consumed just 41% of the indirect energy of the region's average urban resident. Household direct energy use depends highly on climate and household wealth while household indirect energy use relates closely with a region's diversity and strength.

From 1997 to 2007, per capita household indirect energy use rose in all regions except in Northeast and Northwest China. Coastal regions enjoyed larger rises than did other regions. Increasing levels of household consumption contributed most to the increment of household indirect energy use. Improved energy efficiency in production and changes in the structure of intermediate inputs offset the rising effects of heightened household consumption in most regions. Population migration played an important role too, causing household indirect energy use to rise in all regions from 1997 to 2007. Migrating households not only increase their wealth but also adopt urban lifestyles after. Moreover, they typically move to more economically developed regions reinforcing the strength of pre-existing economic foundations in their destination regions. Population migration from central and western parts of China to Coastal regions significantly heightened household indirect energy use in the North Municipalities, the East Coast, and the South Coast. Much of this West to Coast migration was also rural to urban in nature. And by increasing need for local production, rapid urbanization significantly increased household indirect energy use in the South Coast, the North Coast, and Southwest China, which urbanized most quickly from 1997 to 2007. Rapid urbanization and population migration from hinterland to coastal regions contributed heavily to the rise of household indirect energy use in China.

As a spatially large and heterogeneous country, it is crucial to identify differences in China's regional household energy consumption patterns as well as the key forces that drive differences in the growth of household energy use to design appropriate regional specific energy conservation policies. This research yields some interesting and relevant implications.

First, the fuel mix of residential direct energy use varies across regions. Even though electricity and natural gas have been substituting for coal in Chinese households, coal remains the most important source for households in China's less-developed North Coast, Central China, Northwest China, and Southwest China. With ongoing fuel substitution, residential electricity demand will increase rapidly in these four regions. Since China's power generation system is mainly coal-based, fuel substitution from coal to electricity is only likely to improve households' indoor air quality. Green house gas emissions induced by households are unlikely to decline much beyond present per capita energy consumption levels. Thus, it is very important to encourage households of these regions to adopt *greener* energy uses, including greater direct use of natural gas and solar power. Government could promote the accessibility of these energy sources by providing subsidies or preferential loans for constructing natural gas pipeline networks and for purchasing solar arrays and water heaters. Similarly, it is important to diversify fuel sources for power generation by further encouraging renewable energy. Also, given the utility industry's aging infrastructure, efficiency improvement in power generation and transmission processes could significantly reduce the amount of energy embodied in household consumption.

Second, direct household energy use is highly affected by climate. With higher income, more energy will be used to meet households' rapidly rising desire for thermal comfort. Only urban households in northern heating zones currently have access to central heating. Air conditioners are commonly used as heat pumps in winter by households in the East Coast and Central China and by relatively wealthy rural households in northern China. Also, air conditioners will be increasingly used by households for space cooling in summer. In 2009, air conditioners accounted for 20% of China's total electricity consumption and 40% of the summer peak electricity load in large and medium cities (Zhou, 2010). With rising demand for thermal comfort, electricity demand is expected to rise rapidly in all regions, especially in rural areas. Improving the energy efficiency of air conditioners will remain an important way to achieve energy conservation. Thus, China should adopt strigent energy efficiency standards for boilers, furnaces, and air conditioners to improve its overall energy efficiency. At the same time, the Chinese government should promote highly efficient products by labeling, offering subsidies, tax credits, or low interest loans to households to encourage their use.

Third, energy resource endowments do not match up well with energy consumption across regions in China. Energy resources, especially coal, are transported from Northwest and Central China to the coast. Interregional trade also played increasingly important roles in household indirect energy use in all regions from 1997 to 2007. Households increasingly relied on interregional trade to meet their energy needs. Central China, Northwest China, and North China are the main suppliers of household indirect energy use. That is, energy is flowing from Northwest China, Central China, and North China to the coast directly in forms of energy resources, as well as indirectly as energy-intensive goods and services produced in these regions. Energy intensities of these three regions are higher than the national average. Thus, energy efficiency improvements focused on these regions would have a major effect on household energy use across all regions.

Fourth, population migration increased household indirect energy use in all regions. People migrated to economically developed and urbanized coastal areas for better job opportunities. Big cities, such as Beijing, Shanghai, and Guangzhou have high shares of temporary migrants. The large volume of new migrants has reinforced the resource and environmental burdens of these mega-cities. Thus, it is very important to understand the metabolism of mega-cities in China. Sustainable urban expansion of growing megacities is a key challenge for the China's government. More and more rural people will migrate to urban regions for jobs as long as the pay differences persist. Baeumler et al. (2012) projected that China's small and medium-sized cities will experience the greatest increase in urban population over the next 15 years. Rapid urbanization in these cities will lead to a great surge in demand for infrastructure construction as well as city planning. Thus, it is both a challenge and an opportunity for local planners and government to develop these cities in a smart and compact way.

Last but not least, the different energy consumption patterns of urban and rural households indicate that China is still under a dual urban-rural system. Compared to households living in urban areas, rural households are more self-sufficient and, hence, consume less commercial energy both directly and indirectly. With increasing income, rural households will attempt to emulate lifestyles of their urban counterparts. This chapter indicates that the household consumption levels rose more rapidly in urban areas of developed coastal regions. Rising household consumption outpaced energy efficiency gains in household indirect energy use in these places. Thus the energy consumption potential of the household sector looms high. As China relies more on domestic demand rather than on exports to further drive it economy, household energy use is likely to rise even more rapidly in the near future. Thus, besides implementing energy conservation policies in both production and consumption, the Chinese government should also consider securing a supply of energy that is sufficent to meet its rapidly rising household demand for energy.

Chapter 5
Household Level Analysis

5.1 Introduction

China has experienced rapid urbanization since the 1980s. The share of Chinese population that lived in urban areas jumped from 19.4% in 1980 to 46.6% in 2009. People are moving from rural to urban areas for job opportunities and improved living standards. Major disparities in household energy use between urban and rural households means that urbanization is having a significant effect on the nation's household energy consumption.

Many studies investigating household energy consumption in China have used macro-level analytic techniques (some key examples are: Fan et al., 2012; Feng et al., 2011; Guan et al., 2009; Liu et al., 2009, 2011; Peters et al., 2007; Wei et al., 2007). Using input-output analysis, Liu et al. (2011) found that household-consumption-induced CO_2 emissions (both directly and indirectly) accounted for over 40% of all CO_2 emissions generated through primary energy use. Using a consumer lifestyle approach, Wei et al. (2007) quantified direct energy use and indirect energy use and related CO_2 emissions of Chinese household from 1999 to 2002. Household consumption accounted for about 26% of total primary energy use and 30% of all CO_2 emissions in China. Based on Wei et al.'s study, Feng et al. (2011) compared household energy use for different income groups in China and found that income had a significant effect on the amount and structure of household indirect energy use. High-income households tended to consume more energy indirectly through goods and services and had a more-diversified indirect energy consumption structure.

Some research studied household energy requirements at the household-level via survey data (some key examples are: Golley and Meng, 2012; Jingchao and Kotani, 2012;

Niu et al., 2012; Tonooka et al., 2006; Wang et al., 1999; Ye et al., 2011; Zhang, 2010). Household-level analysis can yield a more complete understanding of key behavioral factors behind various household energy consumption choices. Most household-level studies of China have been performed for particular cities or counties. At the national level, Golley and Meng (2012) used *China's Urban Household Income and Expenditure Survey* data to explore the effect of income on urban households' carbon footprints. The lack of nation-wide household-level research on household energy consumption is partly due to the non-existence of national surveys examining on residential energy consumption in China (Chen et al., 2008).

Most literature on household energy use in China have been limited to identifying households as either rural or urban. Households who migrate from rural to urban as for better financial rewards or opportunities are neglected in the literature. They are included only as urban households. This group is quite large and behaviorally quite distinct from urban households. A large share of rural-to-urban migrants live in rented traditional neighborhoods (called "urban villages") and own fewer home appliances (Zhang, 2010). To understand how urbanization affects energy consumption in China, it is important to include this missing group of people since they are the main set of individuals who compose and cause urbanization.

To bridge the gaps, this chapter aims to explore lifestyle differences cross urban, rural, and rural-to-urban households and to investigate key factors affecting household indirect energy use for these three groups of people at the household-level. This chapter is organized as follows. Section 2 lists research questions and outlines the research approach. Section 3 generally describes lifestyle variations across urban, rural, and rural-to-urban households. Section 3 also shows the variations of household indirect energy use of these three types of households and across different regions. Digging further, it explores key factors that drive indirect energy use for different types of households. A final section concludes this chapter and offers suggestions for future study.

5.2 Methodology and Data

This chapter shares descriptive and inferential analysis of the *Chinese Household Income Survey 2002* as in micro data files developed using statistical package SPSS. Two analytical tasks investigate the following two questions:

- What are the lifestyle differences across urban, rural, and rural-to-urban households in China?
- How do key factors such as climate, income, and housing characteristics affect household indirect energy use for each of the above these three types of households?

5.2.1 The Consumer Lifestyle Approach

Bin and Dowlatabadi's (2005) consumer lifestyle approach (CLA) explores the relationship between household consumption activities and their environmental impacts. Based on the CLA, Wei et al. (2007) quantify the direct and indirect energy use and related CO_2 emissions of Chinese households from 1999 to 2002. Feng et al. (2011) use it to compare household energy use and related CO_2 emissions for typical households of different income groups and of different regions in China.

In this chapter, the term "consumer" refers to households or household members. Households use energy directly for lighting, cooking, space heating, and operating electric appliances and for fueling private cars, among other activities. Household indirect energy use refers to energy embodied in goods and services that households consumed. Due to data limitations, household direct energy use for home energy use and personal travel cannot be calculated for the sample households.[1] Household indirect energy use is calculated from their consumption expenditures. This chapter calculates the indirect energy use and related CO_2 emission for each expenditure category through *Equation* 5.1 and 5.2. Based on Wei et al.'s work on the energy intensity and carbon intensity of

[1]The CHIPs is designed to investigate household income, no questions about household energy consumption activities are asked in the survey.

different types of consumption expenditures (see *Table* 5.1).

$$IndirectEnergy = \sum_{i=1}^{8} (EI_i \times X_i) \tag{5.1}$$

$$CO_2 = \sum_{i=1}^{8} (CI_i \times X_i) \tag{5.2}$$

Table 5.1: Consumption Activities and Related Energy and Carbon Intnesity in 2002

Expenditure	Activities	Energy Intensity (Kg SCE/Yuan)	Carbon Intensity (Kg C/Yuan)
Food	Foodstuff, edible oil, meat, poultry and related products, eggs, condiment, candy, cigarettes, alcohol, beverage, dinning out, and food processing services	2.8	2.3
Clothing	Apparel and laundering services	1.8	1.7
Housing Facilities & Services	Durable goods, furnitures, room decorations, household facilities and related maintenance services	0.9	0.8
Health & Medical Service	Drugs and medical service	2.2	1.8
Transport & Communication	Transportation and communication	0.7	0.7
Education, Cultural & Recreation Services	Education, Recreation, and other related activities	5.0	4.3
Residence	Housing, water, electricity, fuel and others	40	28.2
Miscellaneous Goods & Services	Miscellaneous goods and services	2.2	1.9

Source: Energy intensity and carbon intensity data are from Wei et al. (2007)

5.2.2 Multivariate Regression Analysis

In CLA, households' decision making is affected by five major interacting groups of factors: 1) external environmental factors (*e.g.* climate and technological levels); 2) individual determinants (*e.g.* attitudes and personal preferences); 3) household characteristics (*e.g.* housing floor area, household size, and household income); 4) consumer choices (*e.g.* information and availability of goods and services); 5) consequences (*e.g.* consumption related energy use and environmental impacts) (Bin and Dowlatabadi, 2005). As is clear from the first set of factors, household energy consumption varies with local climate conditions. Households in places with modest temperatures have much lower energy consumption levels than households experiencing more extreme temperatures (Glaeser and Kahn, 2010; Zhang, 2004). Beside climate, many macro-level place-based factors such as technology, infrastructure, energy prices, urbanization, and existing policies also play an important role in influencing household energy consumption (Brohmann et al., 2009; Dzioubinski and Chipman, 1999; Ewing and Rong, 2008; Norman et al., 2006; Steg, 2008). At the household level, income is well-known to have a significant and positive effect on household energy consumption (Cayla et al., 2011; Cohen et al., 2005; Lenzen et al., 2006; Moll et al., 2005; Vringer and Blok, 1995). Some demographic factors such as household size and aging structure of household members also substantially affect household energy consumption through ownership and choice of appliances and household behavior (Hamza and Gilroy, 2011; OECD, 2002b; O'Neill and Chen, 2002). Housing tenure also places an important role in household energy use, especially in rented dwellings. Households in rented dwellings tend to consume more energy if heating costs are included in the rental rate (Leth-Petersen and Togeby, 2001). In China, renters use less electricity than homeowners because they own fewer electric home appliances (Zhang, 2010). Household energy consumption is also affected by housing dwelling attributes such as floor area, types of home, and construction materials (Pachauri, 2004). This chapter models household energy use as a function of three major groups of factors: external environment factors (*e.g.* climate, technological level, and energy prices), household characteristics (*e.g.* income, household size, and housing tenure), and housing dwelling attributes (*e.g.* floor area, housing type, and construction materials). Household indirect energy use can be represented by Eq. 5.3.

$$E_i = f(C_i, F_i, H_i) \tag{5.3}$$

where E_i refers to household indirect energy use of the ith household, C_i refers to a vector of external environment variables, F_i refers a vector of household characteristics, and H_i refers to various household dwelling attributes.

Moving from description to inference, this chapter predicts household indirect energy use with ordinary least squares regression. Household size, household income, and housing tenure represent household characteristics, and housing floor area is used to reflect the dwelling's attributes. Heating degree days (HDD) and cooling degree days (CDD) are measures of place-based energy demand for thermal comfort. This is, HDD and CDD are the core variables representing local climate.[2] Due to data limitations, households' geographical locations are used to reflect the effect of other macro-level factors such as technological levels and energy prices. Location in China is specified by residence in one of four broad regions: Eastern Region, Central Region, Western Region, and Northeastern Region. Using the Eastern Region as the base scenario, dummy variables are used to reflect household living in Central, Western, and Northeast Regions. Least squares regression is appropriate for modeling household indirect energy use y, a continuous dependent variable

$$y = \alpha + \beta_1 x_1 + \beta_2 x_2 +, ..., +\beta_i x_i \tag{5.4}$$

where α is the constant of the equation and β_i is the coefficient of explanatory variable x_i. To satisfy normality assumptions, right-skewed variables (indirect energy use, income, and floor area) are subjected to a log transformation. To make the range of regression coefficients readily comparable, variables with large values (HDD and CDD) are divided by 1000.

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[2]The CHIPs survey does not include HDD and CDD data. The degree days are calculated based on the monthly average temperature of households' location when they took the survey. Yearly accumulated HDD and CDD are calculated as follow:

$$HDD = \sum_{i=1}^{12} [n_i \times (T_{hb} - T_i)]^+$$

$$CDD = \sum_{i=1}^{12} [n_i \times (T_i - T_{cb})]^+$$

where T_i is the average temperature for month i; n_i is the number of days of month i; T_{hb} is the base temperature for heating while T_{cb} is the base temperature for cooling. As suggested by Jiang et al. (2009), 18°C (64.4°F) is adopted as the base temperature for heating (T_{hb}) and 24°C (75.2°F) is used as the base temperature for cooling (T_{cb}). The "+" sign in Eq. 5.4 and 5.4 means that only positive numbers are included in the calculation. The monthly average temperature data of major Chinese cities for year 2002 are used to calculated HDD and CDD of major cities (NBS, 2003). Thus, a household sample's HDD and CDD are the HDD and CDD of the city where it locates or of the closest major city of the same province.

5.2.3 Chinese Household Income Survey Projects (CHIPs)

In China, a nationwide residential energy consumption survey has not yet been established (Chen et al., 2008). Instead results of the *Chinese Household Income Projects (CHIPs)* are used. CHIPs has been designed to study the distribution of personal income in China. It is based on waves of face-to-face interviews conducted in both rural and urban areas in 1988, 1995, 2002, and 2007 (Griffin and Zhao, 1993; Riskin et al., 2000; Shi, 2008).[3] CHIPs uses sub-samples from *China National Bureau of Statistics*' national household survey program. As a result, its records are deemed statistically representative of the population of Chinese households.

The 1988 and 1995 CHIP is limited to locally registered urban and rural households. The floating population is not included in these waves. The 2002 CHIP includes *rural-to-urban* migrants who held official rural household registration status but resided in cities during the survey period. To better capture the household consumption patterns of the different household types, the 2002 CHIP dataset is used in this chapter. *Table* 5.2 shows the sample sizes for the sub-datasets of urban, rural and rural-to-urban households.

Table 5.2: Sampling Sizes of Household Datasets of 2002 CHIP

Houehold Type	**Dataset Used**	**Sampling Size**
Urban	DS 2: Urban Household Income, Consumption and Employment Data	6835
	DS 4: Urban Household Assets, Expenditure and Income Condition Data	
Rural	DS 7: Rural Household Income, Consumption, Employment Data, Social Network, Quality of Live and Villege Affair Data	9200
Rural-to-Urban	DS10: Rural-Urban Migrant Household Data	2000

Note: Since DS 2 and DS 4 do not provide total household income, I also use individual total income (*P201*) from *DS 1: Urban Individual Income, Consumption, and Employment Data*. Total household income is the added individual income of all household members. The result is matched with DS 2 and DS 4 through the *Household Number*.

The 2002 CHIPs surveyed 6,835 urban households and 2,000 rural-to-urban households from 26 cities in 12 provinces. In rural areas, it surveyed 9,200 rural households

[3] The CHIP's dataset for year 2007 has been produced, but is not yet publicly available.

from 114 townships in 26 provinces. As suggested by Feng et al. (2011), China is divided into four regions: Eastern Region (North Municipalities, North Coast, East Coast, and South Coast), Central Region (Central China), Western Region (Northwest China and Southwest China), and Northeastern Region (Northeast China). *Table* 5.3 shows the sample sizes of these three types of households by region. Since the representativeness of these three sample household types is unknown, they should not be grouped as one in any analysis.

Table 5.3: Sampling Size of Different Regions of 2002 CHIP

Region	Urban		Rural-to-Urban		Rural	
	Cases	%	Cases	%	Cases	%
Eastern Region	1767	26%	500	25%	2280	25%
Central Region	2486	36%	750	38%	3140	34%
Western Region	1895	28%	550	28%	2850	31%
Northeast Region	697	10%	200	10%	930	10%
Total	6845	100%	2000	100%	9200	100%

CHIPs includes several data fields that are particularly useful for the current study. The survey indicates households' expenditures by types of consumption activity. Household indirect energy use is calculated based on the expenditure data. The survey also gives some description of household characteristics and housing attributes, as shown in *Table* 5.4. In addition to descriptors such as household income, household size, housing tenure, and housing floor area, this survey also indicates whether households own basic housing facilities (*e.g.* sanitary, heating, and kitchen) and different types of home appliances. Together, these items provide a strong basis for understanding the variations of households' lifestyles and household energy use across urban, rural, and rural-to-urban households in China. It is worth noting, however, CHIPs does not include enough details on household energy consumption to build a fully cogent model. It lacks information on utility bills, personal transportation choices, and usage frequency of home appliances.

Table 5.4: Summary Statistics for CHIPs 2002 Variables

Continuous Variables	**N**	**Max**	**Min**	**Mean**	**STDEV**
Urban Households					
Indirect Energy (ton)	6835	5.6	679.0	83.5	47.9
Heating Degree Days (annual, C)	6835	193.5	3754.1	1800.4	944.0
Cooling Degree Days (annual, C)	6835	0.0	587.7	208.9	177.8
Household Income (Yuan)	6835	1,720	179,567	24,401	15,368
Household Size (Person)	6752	1	9	3.0	0.8
Total Usable Area (m^2)	6752	7.0	402.0	53.7	26.3
Rural-to-Urban Households					
Indirect Energy (ton)	1987	0.8	528.9	55.2	45.2
Heating Degree Days (annual, C)	2000	193.5	3754.1	1755.9	966.1
Cooling Degree Days (annual, C)	2000	0.0	587.7	227.6	184.1
Household Income (Yuan)	1999	600	300,000	16,426	16,228
Household Size (Person)	2000	1	9	2.7	1.0
Total Usable Area (m^2)	1988	1.0	300.0	29.1	28.7
Rural Households					
Indirect Energy (ton)	9200	0	340.9	25.6	18.8
Heating Degree Days (annual, C)	9200	193.5	4432.5	1889.7	1132.6
Cooling Degree Days (annual, C)	9200	0.0	587.7	229.6	166.4
Household Income (Yuan)	9199	-1,133	139,458	10,698	8,588
Household Size (Person)	9200	1	12	4.2	1.3
Total Usable Area (m^2)	9200	9.0	768.0	115.6	73.2

Binary Variable	Owner-Occupied?		
	N	Yes	No
Urban Households	6752	5343	1409
Rural-to-Urban HH	2000	223	1777
Rural Households	9180	9089	91

5.3 Results

The results are organized according to the two major research questions in Section 5.2 and their associated analytical tasks. *Figure* 5.4 to 5.9 and *Table* 5.5 to 5.6 present results, which are summarized below.

5.3.1 Variation of Lifestyles

There are large lifestyle disparities across urban, rural and rural-to-urban households. This section describes the variations through household characteristics (income, expenditure, household size, and housing tenure), housing dwelling attributes (housing size, facility, and home appliances), and household indirect energy use and related CO_2

emissions.

As shown in *Figure* 5.4, household size varies across urban, rural, and rural-to-urban households. The average household size for urban and rural households is 3.0 and 4.2 persons, respectively. Rural-to-urban households tend to have smaller household sizes. On average, a typical rural-to-urban household has 2.7 members who lived in the city and 1.3 members who lived in the home village. In 2002, the annual income of a typical urban household was 24,401 Yuan. Typical urban-to-rural and rural households earned only 67% and 44%, respectively, of the average income of their urban counterparts (see *Figure* 5.2). Urban and rural households typically spent about 73% to 74% of their annual incomes. Equivalent rural-to-urban households spent slightly lower shares at 70%. This is because rural-to-urban households typically remit part of their incomes to household members in their home villages.

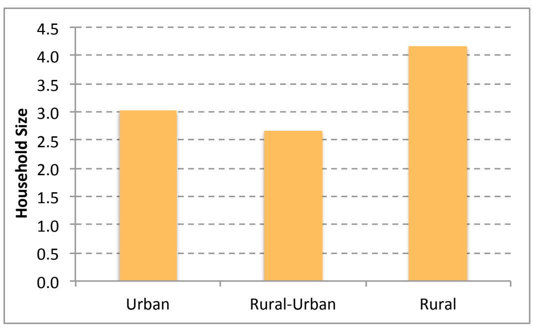

Figure 5.1: Average Household Size of Each Group

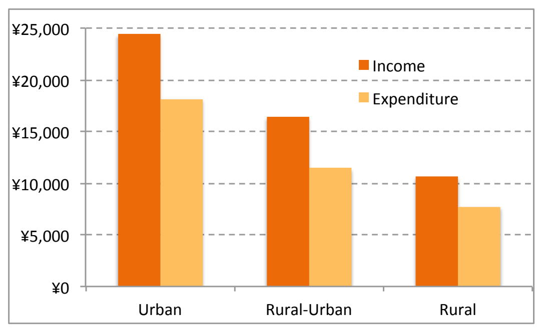

Figure 5.2: Average Household Income and Expenditure in 2002

There are significant variations in house size and housing tenure for urban, rural, and rural-to-urban households. In rural China, almost all houses are owner-occupied. For urban households, 79% of households lived in owner-occupied houses and 16% of urban households lived in houses owned by their working units.[4] Only 5% of urban households lived in rented housing. Over 70% of rural-to-urban households lived in rented urban housing, and only 11% lived in their own homes (see *Figure* 5.5).

The complexity of housing tenure in urban China in 2002 was a result of housing reform since the 1980s. Before the housing reform, nearly all homes in urban China

[4]In China, many work places provided housing to their workers for free or for a discounted price before the housing reform.

were owned and occupied by working places or municipal housing bureaus. Houses were allocated to urban residents through a social housing allocation system. Urban households were charged a nominal rent to help pay for maintenance and housing-related services. The housing allocation system resulted in housing shortages and inferior housing conditions in urban China. Subsequently, housing reform was introduced to privatize work-unit-owned houses and to ameliorate the shortage. In 1998, China terminated the social housing allocation system and required all state-owned workplaces to sell their housing to current residents at a discounted price (He, 2010). A housing market developed in China as a result. In 2002, 62% of urban households lived in housing that had been privatized, and 16% lived in housing still owned by their workplaces. Only 7% of households lived in commercial housing purchased via the newly formed housing market.

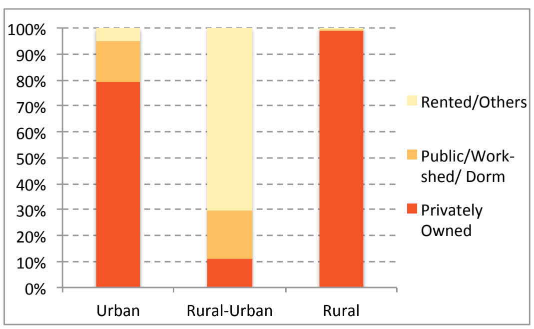

Figure 5.3: Household Home Ownership in 2002

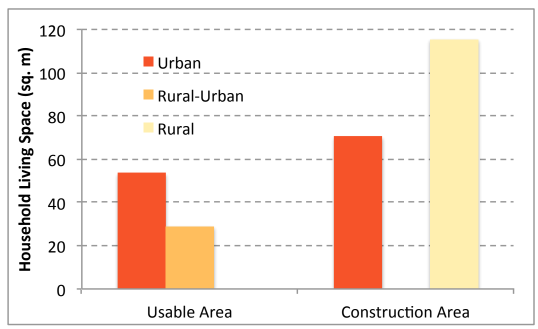

Figure 5.4: The Average Home Usable Area and Home Construction Area

Household living conditions varied widely across urban, rural, and rural-to-urban households. A typical rural-to-urban household lived in a much smaller home than did a typical urban household. In 2002, the average usable floor area for housing was 54 m^2 for an urban household and only 29 m^2 for a rural-to-urban household. Compared to their urban counterparts, rural households had much larger living spaces. The housing construction area of a typical rural household was 116 m^2, 64% higher than the urban level (71 m^2). In rural China, nearly all houses are self-built while the construction of most houses in urban areas was paid for by workplaces and real-estate developers.

Besides floor area, ownership of basic housing facilities (*e.g.* sanitation, heating, and kitchen) varied between urban and rural-to-urban households. In 2002, 58% of urban households lived in housing that had individual bath and toilet rooms. Only 16% of rural-to-urban households had such facilities. Compared to rural-to-urban households, urban households were much more likely to be in housing with central heating or air conditioning. Also, most urban households had independent kitchen facilities while only 42% of rural-to-urban households had such kitchens. Rural-to-urban households' low ownership of basic housing facilities is likely due to their relative lack of income, which undoubtedly also induced their predilection toward renting.

Table 5.5: Household Facilities Ownership of Urban Households and Rural-to-Urban Migrants in China, 2002

Sanitary Facilities			Heating Facilities			Kitchen Facilities		
	Urban	Migrant		Urban	Migrant		Urban	Migrant
Lack Facilities	12%	45%	No Heating	43%	65%	No Kitchen	5%	47%
Have Bath & Toilet	58%	16%	Air Conditioning	14%	5%	Independent Kitchen	94%	42%
Have Toilet, Lack Bath	25%	22%	Central Heating	29%	15%	Shared Kitchen	1%	11%
Shared Facilities	4%	17%	Other Means	14%	15%			

Source: analysis based on CHIPs 2002

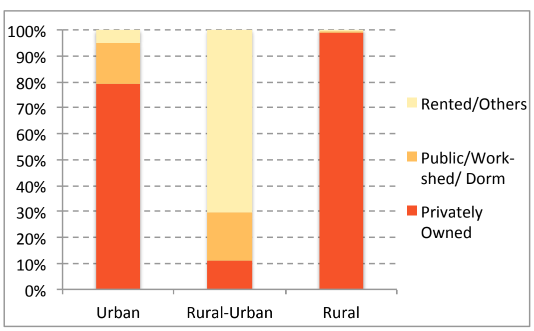

Figure 5.5: Household Home Ownership in 2002 (Source: CHIPs 2002)

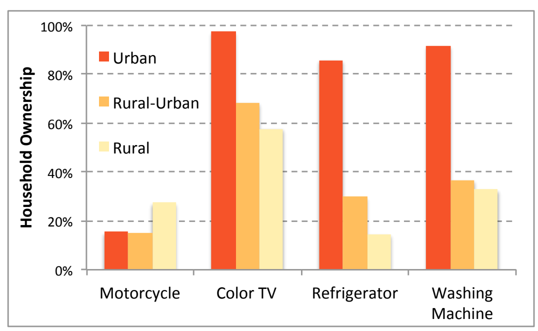

Figure 5.6: Household Home Appliances Ownership in 2002 (Source: CHIPs 2002)

Ownership of home appliances partly reflects households' living conditions (see *Figure* 5.6). Color televisions penetrated all urban households by 2002. However, only 68% of rural-to-urban households and 58% of rural households owned color televisions that year. Most urban households owned refrigerators and washing machines, while only a third of rural-to-urban households owned washing machines. Only 30% for rural-to-urban households and 15% for rural households own refrigerators. The ownership disparity of color televisions, washing machine, and refrigerators across these three types of households undoubtedly is a reflection of income disparities among them. Interestingly, rural households tended to be more likely to own motorcycles than were either urban and rural-to-urban households in 2002. This tendency is likely caused by the lack of available public transportation system in much of rural China and their lower income levels which may disable auto ownership.

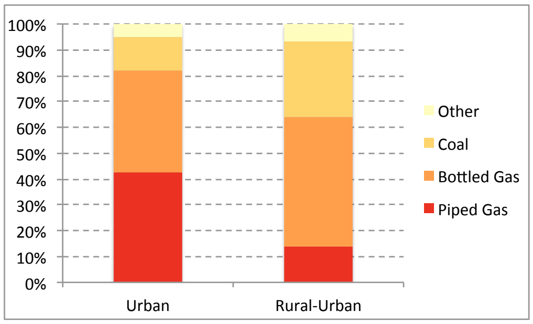

Figure 5.7: Type of Energy Used for Cooking by Households in Urban China (Source: CHIPs 2002)

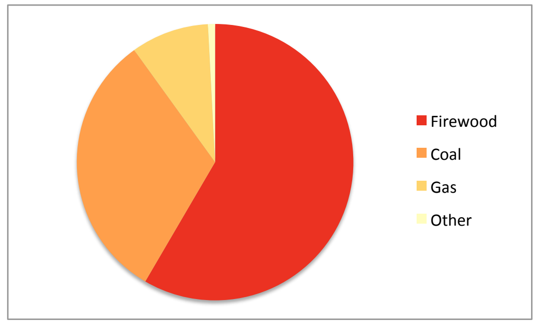

Figure 5.8: Type of Energy Used for Cooking by Households in Rural Area (Source: CHIPs 2002)

Urban and rural households use different types of cooking fuels in China. In 2002, fuels such as firewood and straw were widely used (58%) for cooking by rural households (see *Figure* 5.8). Moreover, a full 32% of rural households used coal as a major cooking fuel and just 9% used natural gas. In urban areas, households often used bottled gas, piped gas, and coal for cooking. Bottled gas played an important role in households' daily lives in urban China in 2002. About 40% of urban households and 50% of rural-to-urban households used bottled gas as their primary cooking fuel (see *Figure* 5.7). Compared to urban households, rural-to-urban households were more likely to use coal and less likely to use piped gas for cooking. Rural-to-urban households are more likely to live in older housing that lack modern infrastructure like gas lines. Since the CHIPs survey did not ask questions about household energy use activities (*e.g.* personal transportation and electricity bills), household direct energy use for urban, rural and rural-to-urban households in 2002 is not available.

5.3.2 Household Indirect Energy Use

Household energy use through goods and services varies among different types of households. In 2002, a typical urban household consumed 83.5 Tons SCE of energy indirectly, 51% higher than a typical rural-to-urban household (55.2 Tons SCE) and 227% higher than a typical rural household (25.6 Tons SCE). Due to indirect energy use, a typical urban Chinese household caused 65.1 Tons of CO_2 emissions to be released into the air in 2002, much higher than typical rural-to-urban and rural households in China (see *Table* 5.6).

Residential expenses are the most energy-intensive household budget category. They include housing payments, housing maintenance and repair, and heating and utility costs. To simplify calculations, only utility expenditures are used to calculate the indirect energy use of residence. Households consume large amounts of energy both directly and indirectly through their consumption of water, heat, electricity, and gas. Large amounts of energy are lost in the production, conservation, and distribution of electricity and heat. In 2002, residential items accounted for 49%, 59%, and 37% of household indirect energy use for urban, rural-to-urban, and rural households, respectively. In 2002, a typical urban household spent 1,015 Yuan on water, electricity, and fuel while a typical rural household only spent 236 Yuan. Rural households were more self-sufficient. Although nearly all rural households had access to electricity by 2002, their electricity consumption remained lower than that of their urban counterparts. As mentioned earlier, over half of rural households use firewood and straw as their main cooking fuels. Also, only 34% of rural households drink tap water. With increased income and accessibility to tap water and commercial fuels, the indirect use of energy by rural households through their residences is expected to rise rapidly.

Household spending on food plays an important role in households' indirect energy use too. In 2002, food consumption accounted for 23% of household indirect energy use for urban and rural-to-urban households and 34% for rural households. Urban households consumed much larger shares of household indirect energy use through education, cultural and recreation services. It accounted for 17% of total indirect energy use for urban households, and 8% and 12% for rural-to-urban and rural households, respectively. The size of a rural-to-urban household was 2.8 persons. Some of these households left their children in their home-villages. This enabled rural-to-urban households' expenditure on education to be lower. Thus, education, cultural, and recreation services reveal a lowest share of indirect energy use for rural-to-urban households.

Table 5.6: Household Indirect Energy Requirements and Related CO_2 Emissions

Expenditure Category	Indirect Energy (Ton SCE)			CO_2 (Tons)		
	Urban	Migrant	Rural	Urban	Migrant	Rural
Food	19.4	12.7	8.6	15.9	10.5	7.1
Clothing	3.2	1.1	0.8	3.0	1.1	0.8
Home facilities & services	1.1	0.3	0.3	0.9	0.2	0.2
Health & medical services	2.8	1.4	1.0	2.3	1.1	0.8
Transport & communication	1.3	0.5	0.4	1.3	0.5	0.4
Education, cultural & recreation	13.9	4.3	3.1	11.9	3.7	2.7
Residence	40.6	32.7	9.4	28.6	23.0	6.6
Others	1.3	2.0	1.9	1.2	1.7	1.7
Total	83.5	55.2	25.6	65.1	42.0	20.3

Household indirect energy use also varies across regions (see *Figure* 5.9). A typical urban household in the Eastern Region consumed 115 Tons SCE of energy indirectly in 2002, while a typical rural household in Western Region consumed only 21 Tons SCE. In general, all three types of households consumed the most energy when in the Eastern Region and consumed the least energy when in the Central or Western Region. Both urban and rural households in the East Region consumed 38% more energy indirectly than did the national average of their types of households in 2002. Household indirect energy use for urban and rural households from the Central and Western regions was 11 to 18 percentage points lower than national average levels. For rural-to-urban households, regional variation is smaller. Rural-to-urban households from the East Region consumed 18% more energy indirectly than the national average, while those from the Central and Western Regions consumed 4% and 12% less energy indirectly than the national average. Household types in the Northeast Region consumed at about national average levels of energy for their household types. For all three types of households, those who lived in the developed Eastern Region tended to consume larger shares of indirect energy via education, cultural, and recreation services, and those who lived in the less-developed Western Region consumed larger shares through expenditures on food. Of course food is a necessity, thus reflecting the lower household income in the West. Regional disparities suggest that the rising potential of indirect energy use by households, especially via education, cultural and recreations services in less-developed regions of China.

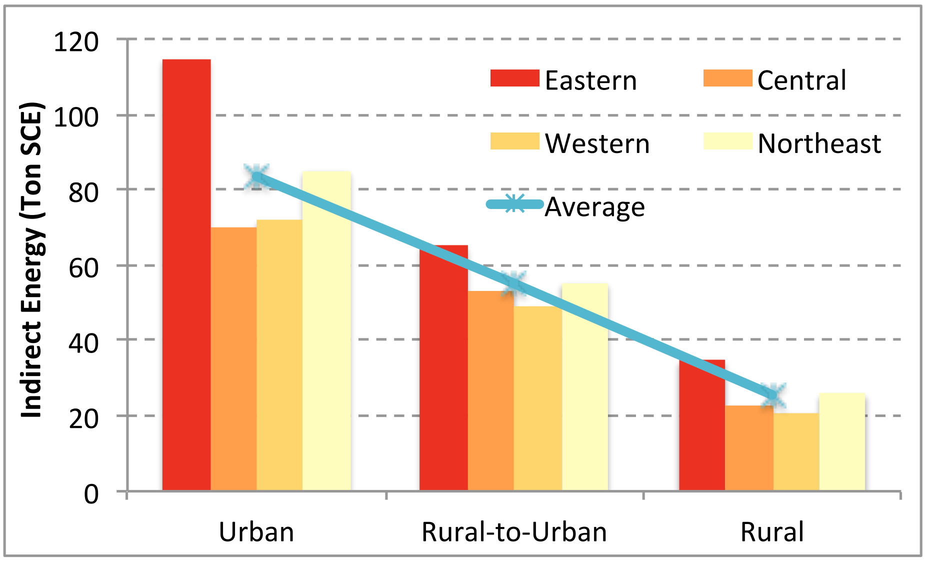

Figure 5.9: Household Indirect Energy Requirements of Each Region

5.3.3 Key Factors Affecting Household Indirect Energy Use

This chapter also examines key factors that affect household indirect energy use. The base model of indirect energy use by households is estimated by using explanatory factors: climate (degree days), housing itself (floor aea), and household characteristics (income, household size, and housing tenure). *Table* 5.8, 5.9, and 5.10 show the Pearson coefficient matrix of these variables and household indirect energy use (dependent variable) for the samples of urban households, rural-to-urban households, and rural households. For all three types of households, CDD, income, household size and floor area all have significant and positive correlation with household indirect energy use. Surprisingly, heating degree days is negatively correlated with household indirect energy use for all three types of households. Most of the independent variables are also significantly correlated with each other in a statistical sense. The variance inflation factor (VIF) test shows that there is no significant collinearity associated with these variables (see *Table* 5.11).

Table 5.7 shows a set of regression models estimating household indirect energy use for urban, rural-to-urban, and rural households in China. In the base model (model 1), expectations are that household indirect energy use increases with degree days, floor area, household size, income, and whether the housing is owner occupied. The base models for urban, rural-to-urban, and rural households are all statistically significant based on a robust F-Statistic. The base model explains 52% of variation of indirect energy use for urban households, 45% for rural-to-urban households, and 27% for rural households. The examination of Beta coefficient suggests that there may be some income thresholds beyond which goods or services in which energy is embodied are purchased to improve households' quality of living rather than basic needs.

Cooling degree days, income, household size, and floor area show the expected relationships with respect to household indirect energy use. The variable for heating degree days also has a coefficient that is statistically significant for all three types of households. However, it runs counter to expectation for rural-to-urban households, with cold climate conditions associated with less household indirect energy use. Because building codes vary with climate, they may mitigate the effect of heating degree days in this analysis. Also rural households from the interior may tolerate better moderate temperature. Housing tenure does not have a statistically significant effect on household indirect energy use. Since little literature focuses on the expenditure behavior of this group of households, this counter-intuitive finding deserves further investigation. Such study will not be performed in the course of this dissertation however. As mentioned before, nearly all houses are owner-occupied in rural China. In urban areas, both urban and rural-to-urban households experienced a transition from the social housing allocation system to a market-based one in 2002. Thus, housing tenure did not have a statistically significant effect on household indirect energy use for any of the three household types in 2002.

Comparing standardized regression coefficients (betas in *Table* 5.7) for the statistically significant variables, the income elasticities are the most influential for all three types of households. A one percentage increase in household income lead indirect energy to rise 0.59% for urban households, 0.50% for rural-to-urban households, and 0.37% for rural households. The variable for cooling degree days was the next most influential factor for urban and rural households. Every 1000 Celsius rise in annual cooling degree days lead household indirect energy use to rise by an average of 0.63% for urban households, 0.22% for rural-to-urban households, and 0.77% for rural households. Compared to that for cooling degree days, the influence of heating degree days is minor. Household size and floor area are somewhat less important for urban and rural households. For rural-to-urban households, household indirect energy use will rise 0.18% if the household size increase by one person. Also, a one percent increase in usable floor area leads on average to 0.15% rise in indirect energy use for a typical rural-to-urban household.

The advanced models (model 2) for each household type include dummy variables of geographical regions of residence to represent external environmental factors beside local climate. In this chapter, China is divided into four regions: Eastern, Central, Western, and Northeast Region. Using Eastern Region as the reference, three location dummy variables (Central Region, Western Region, and Northeast Region) are added to the base model. These binary location variables increase the explanatory power of the OLS regression for household indirect energy use for all three types of households (see *Table* 5.7). However, these variables also induce moderate multicollinearity issues in the OLS regression. As shown in *Table* 5.11, the VIF test of HDD and CDD is close to or around 5.0 in the advanced models. However, they still shed some light on how geography matters in household indirect energy use.

After adding the location variables, the effect of heating degree days becomes statistically insignificant for rural households. Rural households do not have access to central heating in cold regions. They tend to wear more clothing, and add blankets, or use hot water bottles during cold winter periods. Compared to their counterparts who lived in the Eastern Region, all three types of households who lived in the Northeast were associated with higher indirect energy use in 2002 (holding other variables constant). Urban and rural households in the Central Region tended to use less indirect energy compared to their counterparts in the Eastern Region. Living in the Western Region had different affects on indirect energy use for households in urban areas and rural areas. Urban and rural-to-urban households in the Western Region consumed more energy indirectly than their Eastern counterparts, while rural households in the Western Region consumed less energy indirectly than rural households in the Eastern Region. After controlling for climate, housing attributes, and household characteristics, locations still had statistically significant roles in energy-use decision made by urban, rural, and rural-to-urban households. In summary, it is clear that place-based factors beyond just temperature are important to households' indirect energy use. Thus, more inquiry into this line of research is deserved in the Chinese context.

Table 5.7: OLS Regression Models Explaining Household Energy Requirements

Predictor	Urban				Rural-to-Urban				Rural			
	Model 1		Model 2		Model 1		Model 2		Model 1		Model 2	
	B	Beta	B	Beta	B	Beta	B	Beta	B	Beta	B	Beta
(Constant)	4.792*** (0.082)		4.936*** (0.091)		5.026*** (0.188)		5.001*** (0.210)		5.524*** (0.101)		5.920*** (0.109)	
HDD	0.051*** (0.006)	0.092	0.100*** (0.010)	0.179	-0.062** (0.019)	-0.078	-0.068* (0.028)	-0.087	0.067*** (0.008)	0.119	0.009 (0.009)	0.016
CDD	0.632*** (0.033)	0.215	0.982*** (0.054)	0.333	0.222* (0.102)	0.054	0.448*** (0.161)	0.109	0.786*** (0.052)	0.204	0.743*** (0.060)	0.193
Income	0.592*** (0.008)	0.645	0.556*** (0.008)	0.606	0.501*** (0.020)	0.447	0.494*** (0.021)	0.441	0.370*** (0.009)	0.390	0.339*** (0.010)	0.356
HH Size	0.067*** (0.006)	0.102	0.070*** (0.006)	0.105	0.183*** (0.014)	0.233	0.179*** (0.014)	0.229	0.054*** (0.004)	0.111	0.068*** (0.005)	0.138
Floor Area	0.026* (0.011)	0.022	0.049*** (0.011)	0.042	0.148*** (0.020)	0.155	0.148*** (0.020)	0.154	0.111*** (0.011)	0.096	0.118*** (0.011)	0.103
Ownership	-0.011 (0.012)	-0.009	-0.015 (0.012)	-0.012	0.057 (0.045)	0.024	0.033 (0.046)	0.014	0.022 (0.058)	0.003	0.019 (0.056)	0.003
Central			-0.164*** (0.012)	-0.150			0.017 (0.035)	0.011			-0.205*** (0.016)	-0.152
Western			0.049** (0.018)	0.042			0.102* (0.052)	0.060			-0.102*** (0.019)	-0.074
Northeast			0.042* (0.019)	0.024			0.249*** (0.059)	0.099			0.244*** (0.027)	0.115
# of Cases	6751				1973				9173			
F(df)	1220(6)***		894(9)***		272(6)***		186(9)***		567(6)***		443(9)***	
Adjust R^2	0.520		0.543		0.452		0.457		0.270		0.303	

[a] Ordinary least squares regression analysis. The equation predicts the log of household indirect energy use. Income and floor area are subjected to a log transformation to enhance the normality of their distribution. Heating degree days (HDD) and cooling degree days are divided by 1000 to improve the readability of the coefficient.

[b] Due to data availability, floor area means total usable area for urban and rural-to-urban households. For rural households, it refers to total construction Area.

* Significant at 0.05 level; ** Significant at 0.01 level; *** Significant at 0.001 level.

5.4 Conclusions and Outlooks

Household lifestyles in China vary among urban, rural, and rural-to-urban households. Compared to rural households, urban households have higher income and higher ownership of nearly all kinds of home appliances. Meanwhile rural households tend to own more motorcycles. This maybe due as much to their lower relative incomes as to their isolation from public transit. Rural households usually have larger households and, hence, larger homes. In 2002, most rural households in China still did not have access to tap water and used firewood or straw as their main cooking fuels. Rural-to-urban households are rural households who move to urban areas for better job opportunities. Compared to rural households, they tend to have a more urban lifestyle with higher income and home appliance ownership. Compared to urban households, rural-to-urban households are more like rural households and have less income. As a result, they are less likely to have home appliances and housing facilities. Also, in cities rural originated households tend to have smaller households and live in housing with less floor area. In 2002, a typical urban household consumed 51% more energy indirectly than a typical rural-to-urban household, and 227% more than a typical rural household. Thus, urbanization clearly has an important effect on household indirect energy use.

Household indirect energy is affected by climate, household income, household size, and housing floor area. Of these, income most affects household indirect energy use. Moreover, the income effect is higher for urban households than it is for either rural-to-urban or rural households. Cooling degree days was the next most influential factor for urban and rural households. Compared to their urban and rural counterparts, rural-to-urban households' indirect energy uses are less sensitive to cooling degree days. Geographical location also affects household indirect energy use in important ways. Households in the Northeast Region consumed more energy than did the same type of households in other regions. Urban and rural households in the Central Region consume less energy than their counterparts in the Eastern Region. Compared to their counterparts in the Eastern Region, urban and rural-to-urban household in the Western Region consumed *more* indirect energy while rural households in the Western region consume *less* indirect energy. Interregional migration, clearly will continue to have important effects on household indirect energy use. The statistically significant effect of location variables also indicate that location-related external variables such as energy prices and local energy conservation policies may have important effects on household indirect energy use.

This chapter displays household lifestyle differences among urban, rural, and rural-to-urban households, calculates household indirect energy use based on CHIPs survey data of household expenditure, and explores the key driving factors of household indirect energy use for these three types of households. This research yields some interesting and relevant implications.

First of all, there are substantial variations in household energy use between urban and rural households. Rapid urbanization plays an important role in increasing residential energy consumption in China. However, few energy-use studies looked at rural-to-urban households, those who migrate to urban areas for better job opportunities. After migrating to urban areas, rural-to-urban households start to adopt an urban lifestyle with higher household indirect energy use. However, a large part of these households live in rented small houses and lack basic housing facilities. To understand how urbanization affects household energy use, it is very important to study more deeply the consumption behaviors of rural-to-urban households.

Second, household income has a substantial positive effect on household indirect energy use. This research shows that the income effect is higher for relatively rich urban households. Urban households are increasingly trying to emulate Western lifestyles and thus, inadvertently, Western levels of energy use and CO_2 emission. Also, rural households in China will undoubtedly use more energy directly and indirectly as they have more accessibility to commercial energy and have higher financial capacity to afford more goods and services. Thus, it is important for China to guide its households' lifestyles toward more sustainable ways of living as the country maintains its fast track toward modernization.

Last but not least, the CHIPs survey data used in this chapter is for year 2002.

In the late 1990s and early 2000s, households in urban China had experienced a transition from a social housing allocation system to a housing market. The study here cannot show the effect of housing tenure on household energy use. Thus, a more recent wave of the dataset should be used in future studies. Also, the CHIPs survey targets household income and expenditure. Few survey questions ask about household consumption behavior, housing attributes, and efficiency of energy-consuming accoutrements in the household. Since residential energy consumption in China is becoming a more important part in total energy consumption, it is urgent for China to follow the practices of the US and the European Union, and to design a nationwide residential energy consumption survey to monitor its progress.

5.5 Appendix

Table 5.8: Binary Pearson Coefficient Matrix of Variables for Urban Households

		Indirect Energy	HDD	CDD	Income	HH Size	Floor Area
Indirect Energy	Pearson	1	-0.139**	0.285**	0.688**	0.219**	0.218**
	Sig.		0.000	0.000	0.000	0.000	0.000
HDD	Pearson	-0.139**	1	-0.667**	-0.103**	-0.007	-0.205**
	Sig.	0.000		0.000	0.000	0.590	0.000
CDD	Pearson	0.285**	-0.667**	1	0.170**	0.063**	0.177**
	Sig.	0.000	0.000		0.000	0.000	0.000
Income	Pearson	0.688**	-0.103**	0.170**	1	0.156**	0.256**
	Sig.	0.000	0.000	0.000		0.000	0.000
HH Size	Pearson	0.219**	-0.007	0.063**	0.156**	1	0.143**
	Sig.	0.000	0.590	0.000	0.000		0.000
Floor Area	Pearson	0.218**	-0.205**	0.177**	0.256**	0.143**	1
	Sig.	0.000	0.000	0.000	0.000	0.000	

**. Correlation is significant at the 0.01 level (2-tailed).

Table 5.9: Binary Pearson Coefficient Matrix of Variables for Rural-to-Urban Households

		Indirect Energy	HDD	CDD	Income	HH Size	Floor Area
Indirect Energy	Pearson	1	-0.228**	0.263**	0.586**	0.414**	0.391**
	Sig.		0.000	0.000	0.000	0.000	0.000
HDD	Pearson	-0.228**	1	-0.724**	-0.163**	-0.113**	-0.114**
	Sig.	0.000		0.000	0.000	0.00	0.000
CDD	Pearson	0.263**	-0.724**	1	0.200**	0.136**	0.240**
	Sig.	0.000	0.000		0.000	0.000	0.000
Income	Pearson	0.586**	-0.163**	0.200**	1	0.272**	0.318**
	Sig.	0.000	0.000	0.000		0.000	0.000
HH Size	Pearson	0.414**	-0.113**	0.136**	0.272**	1	0.289**
	Sig.	0.000	0.000	0.000	0.000		0.000
Floor Area	Pearson	0.391**	-0.114**	0.240**	0.318**	0.289**	1
	Sig.	0.000	0.000	0.000	0.000	0.000	

**. Correlation is significant at the 0.01 level (2-tailed).

Table 5.10: Binary Pearson Coefficient Matrix of Variables for Rural Households

		Indirect Energy	HDD	CDD	Income	HH Size	Floor Area
Indirect Energy	Pearson	1	-0.114**	0.237**	0.478**	0.206**	0.275**
	Sig.		0.000	0.000	0.000	0.000	0.000
HDD	Pearson	-0.114**	1	-0.734**	-0.128**	-0.067**	-0.271**
	Sig.	0.000		0.000	0.000	0.000	0.000
CDD	Pearson	0.237**	-0.734**	1	0.234**	0.048**	0.247**
	Sig.	0.000	0.000		0.000	0.000	0.000
Income	Pearson	0.478**	-0.128**	0.234**	1	0.193**	0.358**
	Sig.	0.000	0.000	0.000		0.000	0.000
HH Size	Pearson	0.206**	-0.067**	0.048**	0.193**	1	0.196**
	Sig.	0.000	0.000	0.000	0.000		0.000
Floor Area	Pearson	0.275**	-0.271**	0.247**	0.358**	0.196**	1
	Sig.	0.000	0.000	0.000	0.000	0.000	

**. Correlation is significant at the 0.01 level (2-tailed).

Table 5.11: The Variance Inflation Factor (VIF) Test of Independent Variables for OLS Models

	Urban		Rural-to-Urban		Rural	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
HDD	1.83	4.36	2.12	4.54	2.24	3.45
CDD	1.82	4.92	2.22	5.53	2.27	3.22
Income	1.11	1.25	1.17	1.26	1.22	1.35
Household Size	1.04	1.04	1.13	1.15	1.06	1.15
Floor Area	1.30	1.32	1.50	1.53	1.24	1.25
Housing Tenure	1.20	1.21	1.29	1.36	1.00	1.00
Central Region		1.82		1.85		1.75
Western Region		3.68		3.45		2.51
Northeast Reagion		1.80		1.98		2.18

Note: variables with right-skewed distributions (indirect energy use, income, and floor area) are all subject to log transformations, so they do not violate standard normality assumptions of ordinary least square regression.

Chapter 6

Conclusions

In the recent three decades, China's rapid GDP growth has been mainly driven by exports and investment. Households' share of GDP is comparatively low, however, accounting for just 35.6% of GDP in 2009, far lower than that in the U.S. (71.1%) or India (57.5%). As a result, growth in residential energy consumption has been lagging total energy use in China. The residential share of energy use (direct use) decreased from 19.8% in 1987 to 11.2% in 2007. Household consumption's low share of GDP and the low share for households among all direct energy uses points out why China's energy conservation policies have tended to focus on industries but largely neglected households.

China's current investment- and export-led economy has caused a "lack of balance, coordination, and sustainability." As a result, Beijing has been boosting domestic demand to provide future stability. That is, it is backing off its policy of encouraging savings and instead embracing a Western-style consumer society. Thus, the nation's ongoing urbanization and income-driven lifestyle change should cause household energy consumption to rise significantly. Considering the size of China's population, its severe energy security problem, and environmental pressures, it is prudent to understand past trends in household energy use to help China pursue a model with deeper energy savings.

This dissertation is an attempt to explore household energy consumption trends and to identify factors affecting household energy consumption at the national, multi-regional, and household level. Doing so yields insight into how changes in China's technology, urbanization, and lifestyle are likely to further affect energy use by its households. Also, it suggests policies for how China might guide such lifestyle changes toward a low carbon economy as domestic demand vaults over both exports and investment to become a main driver of China's economy. Specifically, the goal of this dissertation is to answer the following questions.

- What have been the core patterns and changing trends for residential energy use in China from 1987 to 2007?
- What are the key drivers of household indirect energy use and what are the relative contributions of these factors?
- How does household lifestyle changes in China affect residential energy consumption?
- What are the regional disparities of household energy use across China?
- At the regional level, what are the key factors that affect household indirect energy use in China?
- At the household level, what are the lifestyle differences across urban, rural, and rural-to-urban households in China?
- How do key factors such as climate, household characteristics and housing attributes affect household indirect energy use?

The answers that were discovered to these questions over the course of this research are summarized below.

6.1 Summary of Chapters

What are the composition patterns and changing trends of residential energy use in China from 1987 to 2007?

From 1987 to 2007, household energy use (both directly and indirectly) increased at an average annual rate of 3.6% from 476 Mtce in 1987 to 960 Mtce in 2007. Households use more energy indirectly through goods and services than directly at home or for personal transportation. In 2007, indirect energy accounted for 61% of total household energy use for rural households and 76% for urban households. There are huge disparities in energy use between urban and rural households. This gap grew from 1987 to 2007. In 2007, a typical urban resident consumed 80% more energy directly than their rural counterparts (267 kg SCE versus 148 kg SCE) and 274% more energy indirectly (868 kg SCE versus 232 SCE). The gap in household energy use suggests that the potential for energy use by Chinese rural households is high. In general, combining both direct and indirect energy use, households accounted for a larger part of total energy use in China. Thus, it is very important for China to target households for education about and incentives for energy reduction options.

What are the key drivers to household energy use and the contributions of these factors?

Fuel mix change is likely to have a substantial effect on changes in household direct energy use. From 1987 to 2007, direct use of coal in households fell steadily while electricity rapidly penetrated the daily lives of both urban and rural households. In 2007, urban residents nearly fully replaced coal through the use of electricity, natural gas, and LPG. Rural households have more work ahead to gain parity.

This dissertation also decomposed energy used indirectly by households into six factors: changes in total population, changes in the urbanization rate, changes in energy efficiency, changes in sub-industrial structure, changes in household consumption structure, and changes in per capita household consumption. Results indicated that per capita household consumption drove the increase while energy efficiency improvements offset a large part of the increment from 1987 to 1997. From 1997 to 2007, energy efficiencies actually fully offset the energy use rises caused by increasing per capita household consumption. However, from 2002 to 2007, changes in the national production structure and in the structure of household consumption actually caused household indirect energy use to rise at an average annual rate of 1.9% and 0.7%, respectively. Also both total population growth and urbanization caused household indirect energy use to increase between 1987 and 2007. Demographic factors, especially urbanization became a major factor driving household indirect energy use in China.

How do household lifestyle changes in China affect residential energy

consumption?

Since 1980s, people's lifestyles in China have changed from fulfilling basic needs toward pursuing higher living standards. By examining four aspects: housing, ownership of home appliances, space heating and cooling, and personal mobility, this dissertation demonstrates the nature of lifestyle changes in China. Increases in living spaces, electric appliance ownership, the demand for heating and cooling, and personal mobility characterize China's burgeoning residential sector. These lifestyle changes lead Chinese households to demand more energy both directly and indirectly.

What are the regional disparities of household energy use in China?

This dissertation divides China into eight regions: Northeast China, North Municipalities, North Coast, East Coast, South Coast, Central China, Northwest China, and Southwest China. Household energy use varies across these regions. In 2005, per capita direct energy use varied from 519 kg SCE in the North Municipalities to 162 kg SCE in Southwest China. Generally residents in northern China consumed more energy directly did their southern counterparts. Regional differences in energy embodied in household consumption are also large. In 2007, urban households in the East Coast consumed 1133 kg SCE energy per capita indirectly, while their counterparts in Southwest China consumed just 708 kg SCE per capita. Households in China's relatively developed coastal regions consumed more indirect energy than did households in its interior. The disparities in household indirect energy use between urban and rural residents within most regions are even larger. In general, household direct energy use depends highly on climate and household wealth while household indirect energy use relates closely with a region's economic diversity and strength.

Based on a multi-regional level analysis, what are the key factors that affect household indirect energy use in China?

From 1997 to 2007, indirect energy use by households increased 16.7% from 610 Mtce to 712 Mtce. Per capita household indirect energy use rose in all regions except Northeast and Northwest China. Coastal regions enjoyed larger rises than did other regions. Increasing levels of household consumption contributed most to the increment of household indirect energy use. Improved energy efficiency in production and changes in the structure of intermediate inputs offset the rising effects of heightened household consumption in most regions. Population migration caused household indirect energy use to rise in all regions from 1997 to 2007. Population migration from central and western parts of China to coastal regions significantly heightened household indirect energy use in the North Municipalities, the East Coast, and the South Coast. Much of this West to Coast migration was also rural to urban in nature. Migrating households not only increased their wealth but also attempted to adopt urban lifestyles. Through demand for local production, rapid urbanization significantly increased household indirect energy use in the South Coast, the North Coast, and Southwest China, which urbanized rapidly from 1997 to 2007. In general, rapid urbanization and population migration from hinterland to coastal regions contributed heavily to regional differences in the rise of household indirect energy use across China.

At the household level, what are the lifestyle differences across urban, rural, and rural-to-urban households in China?

In 2002, a typical urban household consumed 51% more energy indirectly than did a typical rural-to-urban household, and 227% more than a typical rural household. Compared to rural households, urban households have higher income and higher ownership of nearly all kinds of home appliances. A greater share of rural households tended to buy motorcycles. However, this is probably due not only to their inability to purchase autos but also to the lack of public transit in their isolated location. Rural households usually have larger households and larger homes. In 2002, most rural households still did not have access to tap water and used firewood or straw as their main cooking fuels. Rural-to-urban households are rural households who move to urban areas for better job opportunities. Compared to rural households, they tend to have a more urban lifestyle with higher income and home appliance ownership. Compared to urban households, they have a more rural lifestyle with less income and less likely to have home appliances and housing facilities. Also, they tend to have smaller households and live in housing with less floor area.

How do key factors such as climate, household characteristics, and housing attributes affect household indirect energy use?

At the household level, household indirect energy in China is significantly affected by climate, income, household size, and housing floor area. Of these, income is the most influential factor. Moreover, the income effect is higher for urban households than it is for either rural-to-urban or rural households. Cooling degree days was the next influential factor for urban and rural households. Compared to their urban and rural counterparts, rural-to-urban households' indirect energy use is less sensitive to cooling degree days. The effects of household size and housing floor area are moderate. Geographical location also has an important effect on household indirect energy use. In 2002, households in the Northeast Region consumed more energy than did the same type of households in other regions. Urban and rural households in the Central Region consumed less energy than their counterparts in the Eastern Region. Compared to those who lived in the Eastern Region, household lived in Western urban areas consume more indirect energy while rural households in the same region consumed less indirect energy. Clearly, interregional migration will continue to have important effects on household indirect energy use.

6.2 Policy Suggestion

Based on these descriptive, decomposition, and multivariate analyses, several recommendations can be made for China to guide its residents' lifestyles toward more sustainable living.

- Chinese households "moved up" the consumption ladder as their incomes rised. China's newly formed middle class has being emulating a Western lifestyle. Compared to households living in urban areas, rural households are more self-sufficient and, hence, consume less commercial energy both directly and indirectly. This also means they have more potential to increase energy demand if they continue a desire to emulate their urban counterparts. Also, household consumption levels rose more rapidly in urban areas of developed coastal regions. Thus the energy consumption potential of the household sector looms high. As China relies more on domestic demand to drive it economy, household energy use is likely to rise even more rapidly in the near future. Thus, besides implementing energy conservation policies, China should also consider securing a supply of energy that is sufficient to meet it rapidly rising household demand for energy.

- Although electricity and natural gas have been substituting for coal in Chinese households, coal remains the most important source for households in less developed central and western part of China. Also, coal remains the dominant source for generating electricity and central heating. Rising power and space heating will cause the demand for coal to increase further. Thus China should further encourage renewable energy and promote clean-coal technologies in power generation. Also China should gradually switch from coal to more efficient and clean gas (domestically mined) for space heating.

- With higher income, households will use more energy to meet their rapidly rising desire for thermal comfort. Since only urban households in northern heating zones have access to central heating, air conditioning units are commonly used as heating pumps in winter by wealthier households in non-heating zones. Also, air conditioners are increasingly being used by households for space cooling in the summer. Thus improving the energy efficiency of air conditioners is likely to be an important way to achieve energy conservation. China should adopt stringent energy efficiency standards for air conditioners and promote highly efficient products by labeling, offering subsidies, tax credits, or low interest loans to households to encourage their use.

- In the northern heating zones, highly subsidized heating undermined producers' and consumers' incentive to save energy. Thus, the national government should adjust the price of heating to reflect its real costs. Current billing systems based on the amount of living space size do not actually charge for the actual consumption of heating. Also, residents of multifamily dwellings have little control of their indoor temperature. China should liberalize its central heating market to encourage energy conservation.

- Energy inefficient buildings and heating systems in China have led to much energy waste. China does not strickly enforce energy conservation through building code. Thus, the national government must play a stronger role in such regulation, and more importantly, enforcement of such codes. Also, the national government should promote energy-saving devices such as double-pane windows in existing building stock. The combined actions would very much improve the overall energy efficiency of China's residential stock.

- Population migration increased household indirect energy use in all regions. Big cities such as Beijing, Shanghai, and Guangzhou have high shares of temporary migrants. The large volume of new migrants has reinforced the resource and environmental burdens of these mega-cities. Sustainable expansion of these growing megacities is a key challenge for China's government. Also, rapid urbanization in China's small- and medium-sized cities will lead to a great surge in demand for construction as well as city planning. It is both a challenge and an opportunity for local planners and government to develop these cities in a smart and compact way.

- Sustainable household consumption needs the united work of government, households, and civil society. China's central government should take the lead and actively implement regulations. As the world's largest home appliance producer and consumer, China has the ability to produce high efficiency home appliances. However, the overall energy efficiency of electronic appliances in China is lower than that in developed countries (Fridley et al., 2007). China's government should require more stringent standards or even adopt the strict Japan or EU standards for home appliances to improve the overall energy efficiency level domestically. Also, the national government should coordinate cross-sector policies that may lead to detrimental environmental impacts from household decisions (*e.g.* land-use, infrastructure investment, and relevant macro-economic policies) to give consumers a stronger and more consistent set of signals and incentives to engage in sustainable consumption. Households' demand for environmental sustainable products will concomitantly stimulate the supply of these products. China also needs to become a civil society by encouraging NGOs and media to become better information brokers for both corporations and households. They could play an important role in stimulating governments, corporations, and households to change their energy consumption behaviors toward a more sustainable way.

- China does not have national surveys for residential energy consumption. Thus few research studies Chinas household energy consumption at the micro-level. This dissertation uses CHIPs data to explore key factors that affect household energy use. However, few survey questions ask about housing attributes, energy prices, and the energy efficiency of home appliances. Since residential energy consumption in China is becoming a more important part in total energy consumption, it is urgent for China to build a nationwide residential energy consumption survey. The *Residential Energy Consumption Survey (RECS)* and the Residential Transportation Energy Consumption Survey (RTECS) that administered by the US Energy Information Administration provide good examples for China to build its national statistical system of residential energy consumption. Also, making micro-data available to researchers would be immensely valuable to monitor its advances in energy conservation.

6.3 Significant Contributions

The contributions of this thesis can be summarized in five main points:

1. This dissertation tells a fairly complete story of how lifestyle change, particularly urbanization impacts household energy consumption through the national, multi-regional, and household level analysis. This fundamental analysis leads to more clear insight into viable possibilities for energy conservation in China.

2. At both the national and multi-regional level, this dissertation provides new structural decomposition approaches to explore the effect of proximate driving factors, especially the effect of urbanization.

3. At the regional level, this dissertation examines the variations of household energy

requirements and explores the role of interregional trade of final goods and services in household indirect energy use differences across China's geography.

4. At the household level, this dissertation studies the rural-to-urban households, which are largely neglected by other literature on energy use in China. This group has been responsible for the surge in urbanization. It compares the lifestyle and energy use disparities among urban, rural, and rural-to-urban households and explores key factors that affect household indirect energy use to these three types of households.

5. Few studies of household energy use in China are at the national or regional level. This dissertation use CHIPs survey data to investigate how climate, household characteristics, and housing attributes affect household indirect energy use in China.

6.4 Research Limits and Future Research

This dissertation provides a more detailed description and explanation of household energy consumption in China via past trends, spatial variations and spillovers, and key driving factors. There are a number of limitations of this work that are discussed as follows.

- Non-commercial energy use: All direct energy use in this dissertation refers only to household direct use of commercial energy. Non-commercial energy sources such as firewood, straw, and biogas are also very important energy sources for rural residents. When taking biomass fuel consumption into account, Liu et al. (2012) indicate that per capita direct energy use is actually higher for rural residents than their urban counterparts in China. Chapter 5 indicates that over half of rural households in China were still using firewood and straw as their major cooking fuel in 2002. Omitting non-commercial energy underestimates the direct energy use of rural households. With increased income and accessibility of electricity, rural households in China have being experiencing fuel substitution from inefficient non-commercial energy sources to more convenient commercial energy sources. A more detailed study of fuel substitution in rural China and its influence on rural households' lifestyles is needed.

- Energy price: Energy price has important effect on household energy consumption (Brohmann et al., 2009; Fisher-Vanden et al., 2004; Hang and Tu, 2007; OECD, 2002a). This dissertation fails to capture the effect of energy price on household energy use. In China, energy prices were state-set and heavily subsidized before the 1990s. About 46% of coal and 80% of crude oil was state allocated in 1990 (Garbaccio, 1995). After the deregulation of energy prices during the 1990s, state allocation of energy had been largely eliminated by 1999 (Hang and Tu, 2007). The elimination of state-set price has led to rising relative prices (Fisher-Vanden et al., 2004). Before the housing reform in the 1990s, houses were allocated to urban residents through social housing allocation system. Urban households were charged a nominal rent to help pay for maintenance and housing-related services. Also, heating price is highly subsidized in the heating zone. Current billing systems based on the amount of living space size does not always actually reflect the real heating system. The highly subsidized state-set energy price, social housing allocation system, and distorted billing system of central heating put challenges to the study of energy price effect on household energy use in China.

- Stock impact: Chapter 3 and 4 focus on the changes in the flow of household energy requirements. Household energy requirements are defined as energy consumed directly by households or indirectly through their use of goods and services. This research fails to study the stock of housing and home appliances that has long-term impact on household energy consumption. Also, the effect of energy price is neglected in all levels of analysis. Chapter 3 and 4 use nationwide average prices to construct energy I-O tables. However, urban and rural households pay higher prices for electricity and fuels than do corporations and industries in

China. In indirect energy calculations, application of national average will therefore result in an underestimation of the indirect energy requirement of households. Further, energy prices vary across regions and even among urban and rural areas in the same region. The household level analysis in Chapter 5 fails to capture the price effect to household energy use.

- Method limits: In Chapter 3 and Chapter 4, national and multi-regional input-output tables are used to calculate household indirect energy use and explore the driving factors of changes in indirect energy use. To enable this, I-O analysis are needed to combine energy consumption data with each industrial sector in the I-O tables. The matching process applied may have induced some error since it assumes that all products of a certain industrial sector have the same energy intensity. In Chapter 5, a consumer sustainability approach is applied at the household level to calculate household indirect energy use. This method needs to incorporate environmental input-output analysis to calculate energy intensities of different types of consumption activities. This dissertation simply used energy intensity data from Wei et al. (2007)'s study. A more detailed study of how to link the consumer lifestyle approach to household consumption activities is needed.

- Data Limits: There are data limits for both I-O analysis and the household-level analysis. National and multiregional I-O tables are created by the National Bureau of Statistics or State Information Center. In the analysis, national I-O tables are aggregated into 84 industrial sectors, and multi-regional I-O tables only contain 17 industrial sectors. These aggregated industrial sectors do not properly represent the detail of China's economy. Also, it is hard to relate industrial sectors to household consumption activities in interpreting the results of I-O analysis. Imported goods and services become more available for Chinese households. In national and multi-regional I-O tables, imported goods and services for household use were not separated from all imports. Due to data limits, this dissertation fails to capture the role of imported goods and services to household energy use in China. For household level analysis, the CHIP surveys are designed to target household income and expenditures. Few survey questions in CHIPs ask about household consumption behavior, housing attributes, or the energy efficiency of equipments and appliances. Due to these data limits, household direct energy use for each household cannot be calculated. Also, the CHIPs data used in Chapter 5 is for year 2002. In late 1990s and early 2000s, households in urban China had experienced a transition from a social housing allocation system to a Western-style housing market. Thus a more recent dataset that targets residential energy consumption should made available future studies.

This work provides a means to explore key factors affecting household energy use in China. It is a starting point for examining ways to achieve sustainable consumption and to mitigate both energy security and environmental pressures. A number of opportunities for further study are uncovered from the completion of this dissertation.

- Households consume much energy indirectly via their demands for infrastructure and building construction. In fact, the short lifespan of buildings and infrastructure has become a major issue in China. The average life of a residential building is only 30 to 40 years. Expanding the vintage of buildings and infrastructure could significantly reduce future energy and material demand. Thus, an important expansion of current study is to explore how the stock of infrastructure and building affect household energy consumption in the long run. Several research questions emerge from this line of inquiry. How much material and energy waste is generated by the short lifespan of structures in China? What historical, socio-political, and economic conditions caused this problem to arise? How might regulations, economic incentives, or societal efforts (local or national) be applied to solve this problem?

- Household transportation patterns have changed rapidly in China during the past decade. Private car ownership has soared since 2002 (Shui, 2009). Car ownership becomes a sign of wealth and social status in China. But it has sadly lead to an increase in the demand for petroleum products, which are largely imported in China. This emerging mode of transportation has largely changed the lifestyle of

Chinese households. Middle-class households now tend to live in larger homes in suburbs because they can commute by car. Also, rapidly rising car ownership has caused heavy congestion and air pollution in cities. Understanding how private car ownership affect households' lifestyles and consumption patters as well as related environmental effect is an important topic in future studies. Further capitalizing the negative spillovers of auto use is critical.

- Micro-level study is very important for understanding key factors affecting household energy consumption behaviors. Chapter 5 indicates that climate plays an important role in affecting household indirect energy use. In CHIPs survey, household location data is county-level based. The climate data (degree days) is calculated based on the monthly average temperature of the provincial capital city for households' living location. Better climate data is needed to explore the effect of climate on household energy consumption. With increasing globalization, households in big cities such as Beijing and Shanghai are emulating Western lifestyle in housing preferences and housing consumption decisions (Leichenko and Solecki, 2005). Also, households lived nearby may mimic the lifestyles of their counterparts in big cities. Thus, it be interesting to include dummy variables to show the "big city" effect and distance variables to show spillover effects of these big cities. Also, including indicators of globalization in household level analysis (such as presence of Starbucks in a city) is likely to help explore the effect of globalization on household energy consumption in China.

6.5 Summary

Interacting with urbanization, globalization also plays an important role in household energy consumption in China. As China relies more on imported oil and natural gas, Chinese households' rapidly rising energy demand has placed an increasing pressure on global energy market. China's newly formed middle class has been emulating a Western lifestyle with the purchase of cars, bigger homes, and a cadre of labor-saving devices. During the same time, China's government has being encouraging public transit systems in cities and implementing more stringent energy conservation policies such as building codes and energy efficiency standards for home appliances. It is clearly that China's government tries to emulate Japan to promote more conservative residential energy consumption while its households want to pursue the US style energy and material consumption pattern. Thus, guiding Chinese residents' lifestyle toward more sustainable ways of living is very critical for China to land on a more energy-saving model. This dissertation is only a starting point for examining ways to achieve sustainable consumption in China. Sustainable household consumption needs the united effort of government, households and civil society.

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