Assessment of Low-Carbon Policies for the Chinese Urban Residential Sector at Provincial Level

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Abstract

In recent years, the economy of China has developed rapidly, which directly caused an aggressive growth of energy consumption in the residential building sector. To cope with such an issue, it is necessary to setup a reduction target and promote efficiency policies. Hence, cost effectiveness is rather important in terms of policy enforcement. Thus in this study, an efficiency policy evaluation model was developed to predict district level CO_2 emission and marginal abatement cost (MAC) in the future.

The applied model consists of 3 sub-models. First the CO_2 emission sub-model estimates residential CO_2 emissions through 2050. Next the efficiency scenario sub-model provides 2 low carbon scenarios, of which reference scenario (RS) refers to government-plotted policies, and abatement scenario (AS) refers to OECD countries low carbon plans. Last but not the least the MAC sub-model produces MAC curves to evaluate the cost effectiveness of each policy.

As results, CO_2 emissions in all districts saw a 10-fold increase (2000 level compared) in the frozen technology (FT) level scenario. While in RS the FT compared reduction rates were predicted as 20% (warm area) to 40% (cold area). And in AS the reduction rates could be brought up to 60%. In cold area such like Beijing promotion of eco-appliance appears to be the most expensive policy (MAC=1271 USD per ton). Thermal retrofit is highly effective in Beijing and Shanghai however lost its advantage in Guangdong. The 3 behavioral changes policies performed well as the have strength on both energy consumption saving and cost savings.

In this study the uncertainty analysis has also been applied using Monte Carlo simulation. During the analysis, certain input values have been defined with distributions. Take Beijing's results as an example, percentile range 10% to 90%, reduction rate varied from 41% to 48%. The most influential input value was penetration rate of building retrofit in cold areas and electricity CO_2 intensity in warm areas. The same analysis has been applied on MAC for 31 districts as well.

Basing on the above assay results, this study was able to propose the optimum mitigation plan for each different climatic area.

Dedication

I would like to dedicate this paper to my grandfather. Without your encouragement I would never begin the pursuit of science research. You will always be missed and I cherish all the memories we had.

Acknowledgements

There are many people I would like to acknowledge that contributed to the success of this paper and the completion of my Doctors degree.

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Finally, my thanks go to my family for their love and support. You have been there for every decision I have made. I hope I make you proud.

CONTENTS

Figures

Tables

Chapter 1

Introduction

"We stand now where two roads diverge. But unlike the roads in Robert Frost's familiar poem, they are not equally fair. The road we have long been traveling is deceptively easy, a smooth superhighway on which we progress with great speed, but at its end lies disaster. The other fork of the road – the one 'less traveled by' – offers our last, our only chance to reach a destination that assures the preservation of our earth".

("Silent Spring", 1962)

CONTENTS

Recent years the economy of China has developed rapidly, and with the improvement of living standards, energy consumption and CO_2 emissions have increased significantly. With such a developing economy, the pursuit of convenience, comfort, and new home appliances may increase residential energy consumption and greenhouse gas emissions. It is necessary to implement various energy conservation measures. This chapter gives the general background of this research, and also introduces the organization of the paper.

1.1 Energy Crisis in Chinese Residential Sector

China is the most populous country in the world. With 1 327 million people in 2007, it represents about 14% of the world's population. An estimated 45% of the population lives in urban areas. Latest estimates suggest that China's urbanization rate will increase by nearly 1% annually in the next 15 to 20 years, as a result of which around 300 million people will move from rural areas into cities. Of the total working population, 41% is involved in agriculture, 27% in industry and 32% in services (Xing, 2011).

China covers a land area of 9.6 million square kilometers, making it the fourth-largest country. It is characterized by three climatic zones, tropical, subtropical and temperate. In 2007, China's GDP reached USD 2 400 billion, twice as large as it was in 2000. With China's rapid economic development, the income of Chinese residents has risen steadily. In 2007, the GDP per capita reached USD 1 809, equivalent to USD 7 509 in purchasing power parity terms.

Since 1990, China's economy has grown fourfold, resulting in more than a doubling of energy use. Strong energy efficiency improvements have helped to limit growth in energy use. But the rising dominance of coal in the country's energy mix has meant that energy-related carbon dioxide (CO2) emissions have grown faster than energy consumption (IEA, 2010).

The economy of China has developed so rapidly, that with the improvement of living standards, energy consumption and CO_2 emissions have increased significantly. In addition, from 2000 to 2005, residential gross floor area in Chinese urban areas increased 2.4-fold, from 4.41 billion m2 to 10.77 billion m2, while floor area per capita increased 1.3-fold from 20.3 m2 to 26.1m2. The ownership of domestic appliances has also increased rapidly in urban areas of China. A large proportion of urban households now has fans, refrigerators, washing machines, and color televisions. The surge in ownership of these and other durable goods has increased energy consumption sharply. According to some estimates, space heating consumes more than 80 percent of the total building energy use in China (Gliksman, 2006). In northern urban areas, space heating is supplied by district heating systems. Individual units are not metered for space heating use, and in many cases the residents of large residential complexes cannot adjust their own usage. In most of the district heating areas, the heating cost is billed based on the floor area of the unit. This system undermines the incentive to conserve energy and causes massive amounts of energy to be wasted.

All the evidence above indicates that with a developing economy, the pursuit of convenience, comfort, and new home appliances may increase residential energy consumption and greenhouse gas emissions. Therefore, it is necessary to implement various energy conservation measures.

1.2 Objectives and Subjects

The climate of China is extremely diverse, tropical in the south to subarctic in the north. Monsoon winds, caused by differences in the heat-absorbing capacity of the continent and the ocean, dominate the climate. Alternating seasonal air-mass movements and accompanying winds are moist in summer and dry in winter. The advance and retreat of the monsoons account in large degree for the timing of the rainy season and the amount of rainfall throughout the country. Tremendous differences in latitude, longitude, and altitude give rise to sharp variations in precipitation and temperature within China. Although most of the country lies in the temperate belt, its climatic patterns are complex.

The diversity of the climatic has a huge impact on the energy consumption of buildings. There are 5 climatic areas of built environment design in China: Severe cold area, Cold area, Hot Summer Cold Winter (HSCW) area, Temperate area, and Hot Summer Warm Winter (HSWW) area. (Figure 1.1)

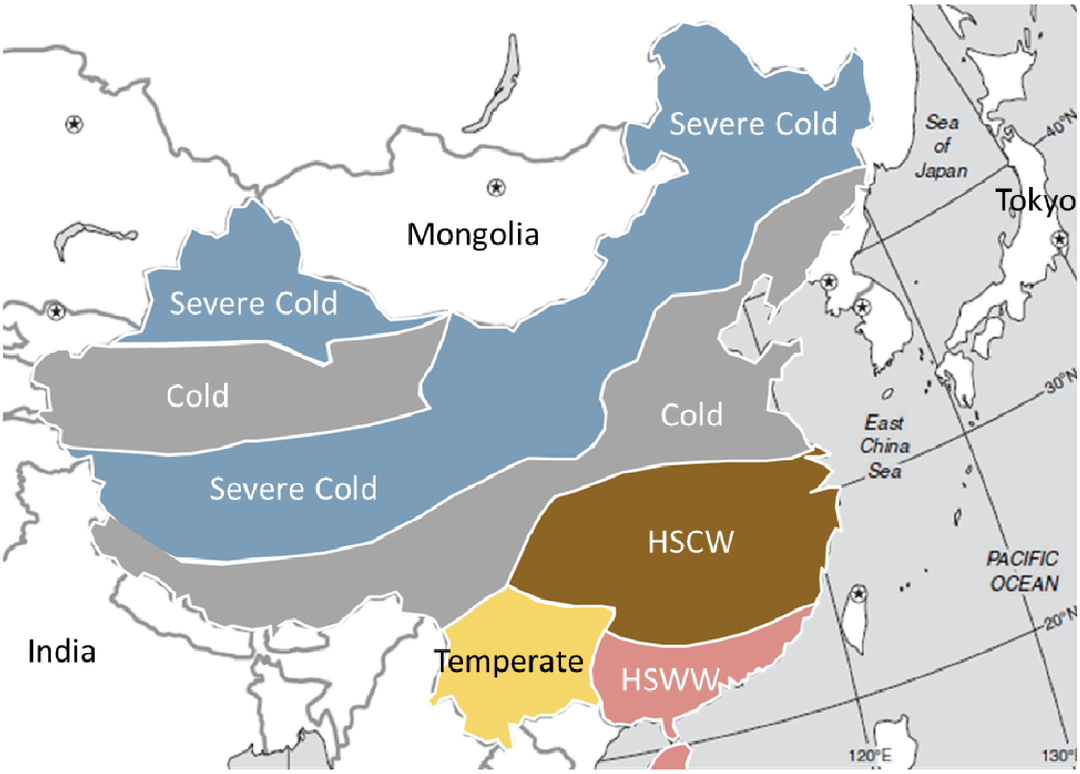


Figure 1.1 China's climate zones

Each climate has distinguishing characters in terms of energy consumption. The northern part of China is located in the severe cold and cold zones, where space heating is the predominant end use for buildings. The HSCW zone covers the central part of China, where space heating and cooling are both required for comfort in buildings. The southern part of China, which falls in the HSWW zone, has seen increasing energy demand for cooling during hot summers.

Besides the climatic characters energy consumption is also distinguished between urban and rural area. First most of the residential buildings in urban area are multi-dwellings, while in the rural area they are detached houses. Also in urban electricity and city gas are wildly used and in rural area the main energy source is biomass energy. Figure 1.2 describes the situation and comparison of urban area and rural area. The annual energy consumption per capita in urban area is almost as twice as it in rural area. Hence, although China was once an agriculture dominated country, urbanization is going so fast in the recent year that the urban population is predicted to surpass the rural population in year 2012. Therefore this study forces on energy issues of urban residential buildings.

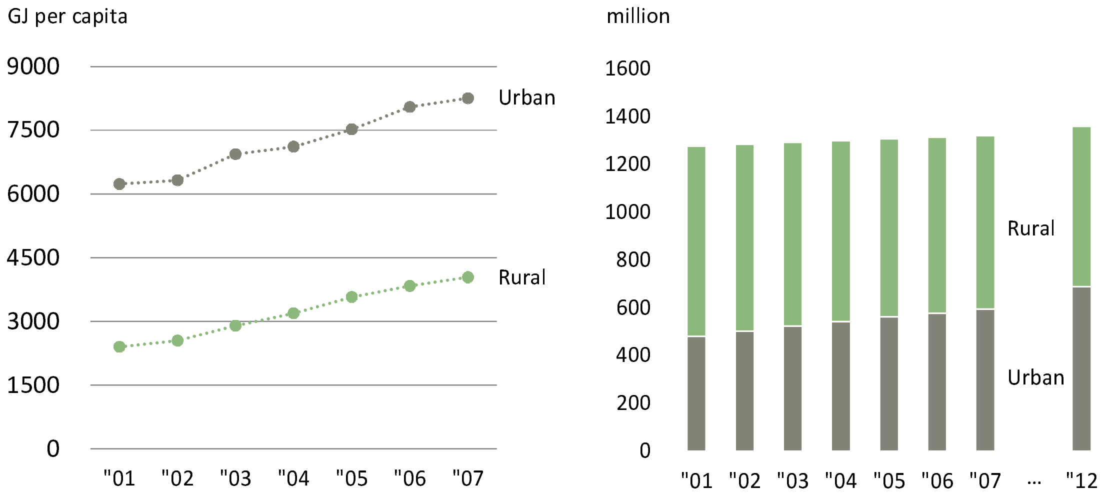


Figure 1.2 Annual energy consumption (left) and population growth (right) of urban & rural areas

Several recent studies have investigated Chinese residential energy consumption. Reports on residential energy consumption are published by the Institute of Building Environment and Equipment Engineering of Tsinghua University every year. Professor Y. Tonooka of Saitama University has proposed to investigate the growth of home appliance use in Shanghai (Ning et al, 2008). Also, Professor H. Yoshino of Tohoku University has led a field study that provided metered data on residential energy consumptions in nine Chinese cities (H. Yoshino, 2009). However, we do not have a clear vision of future growth in energy consumption and lack tools for evaluating the impact of energy saving measures. Thus this study addresses the urban residential buildings and offers visions about the future trend of CO_2 emission as well as assessment of low-carbon policies.

This study first investigated the environmental performance of residential buildings in 31 Chinese provinces. Then, in order to quantify the sustainability of urban residential buildings, it has Chinese urban apartments chosen as subjects for CO_2 emissions estimation. This estimation has been made with consideration of lifestyle changes and global warming countermeasures. The estimation intends to support decision makers in establishing reasonable targets for CO_2 emissions reductions.

This research uses a bottom-up engineering model to project CO_2 emission from urban residential buildings. One of the model's functions is to estimate the CO_2 reduction potential through adoption of efficiency policies. Furthermore, in order to prove that the proposed policies are economically sustainable, the model also evaluates the financial benefits of the efficiency policies by examining their marginal abatement cost.

1.3 Overview of the Thesis

This thesis is divided into 7 chapters as illustrated in Figure 1.3.

Chapter 1 gives a brief introduction of the CO_2 emission problem and an overview of the paper.

Chapter 2 presents the most relevant works that related to assessment of efficiency polices and modeling method of energy system. As examples of system analysis of energy system, this chapter brings in TIMER model from RIVM of the Netherlands, EPPA modes from MIT and Estimation Macro-model for Residential Energy Consumption from Japan. Also, the working principle of marginal abatement cost curve (MACC) is well explained in this chapter.

Chapter 3 proposes an original simulation model that is designed exclusive for evaluating efficiency polices of Chinese urban households. The three sub-models are thoroughly described, as well as their interaction during the simulation.

Chapter 4 introduces the parameter inputs of the model. The inputs are divided into 2 parts. First the basic information, such like household number and floor area have been projected up to 2050 mostly referring to the Chinese year book. Secondly the usages of household appliance have been set up according to reference literatures or reasonable assumptions.

Chapter 5 investigates the reliability of the evaluation model by comparing the model's outputs with statistic data. The initial estimates from CO_2 emission sub-model have showed some mismatches with historical statistical data of year 2000 and 2005. Therefore database and modeling process have been calibrated in order to ensure that the evaluation model is highly able to reproduce the historic trends.

Chapter 6 first gives estimated results of CO_2 reduction potentials and marginal abatement cost. Then the estimated results are applied with uncertainty analysis conducted by Monte Carlo simulation. This chapter also gives an effectiveness assessment of efficiency polices followed by an in-depth discussion.

Chapter 7 summarizes contributions of the thesis, and points out the direction for future works.

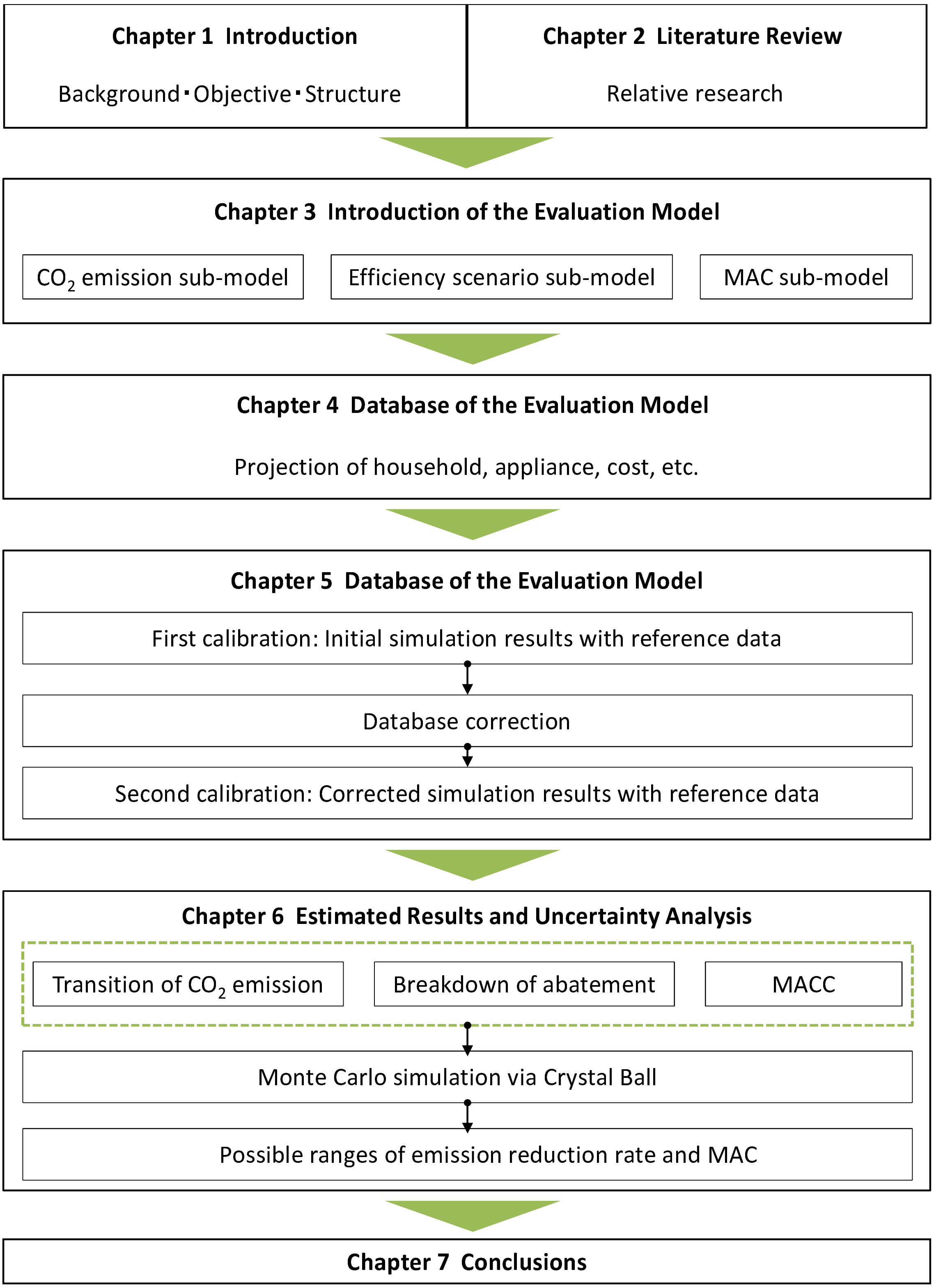


Figure 1.3 Structure of the thesis

Chapter 2

Literature Review

"If I have been able to see further, it was only because I stood on the shoulders of giants".

(Isaac Newton)

CONTENTS

The purpose of this thesis is to assess the effectiveness of household efficiency polices through a projection model. This chapter intends to review the most relevant works that related to assessment of efficiency polices and modeling method of energy system. The point of view from several global institute regard energy issue of Chinese households, the major approach of system analysis research which introduced with 3 simulation models, and evaluation of marginal abatement cost, are discussed later on in this chapter.

2.1 Projection Research of CO_2 Emission

Since the Industrial Revolution in the 1700's, human activities, such as the burning of oil, coal and gas, and deforestation, have increased CO_2 concentrations in the atmosphere. In 2005, global atmospheric concentrations of CO_2 were 35% higher than they were before the Industrial Revolution. Regarding the mitigation and adaptation of the global warming issue, system modeling has become a popular research method.

In the modeling research of CO_2 emissions, it usually provides a baseline scenario and several alternative scenarios. The baseline scenario intends to project the future emission level without any solution. While other alternative scenarios give evaluations of emission reduction potential. Modeling approach is especially effective when the real system is too fragile or impossible to make experiment with, such like the energy supply system in the future. This kind of research is also very valuable for decision makers, because of the various choices it provides with analysis based insights. International Energy Agency (IEA) has proposed a low-carbon scenario *BLUE MAP* and published a series report *Energy Technology Perspectives* (ETP) to describe it. Figure 2.1 shows a projection of energy consumption from Chinese building sector in ETP 2010.

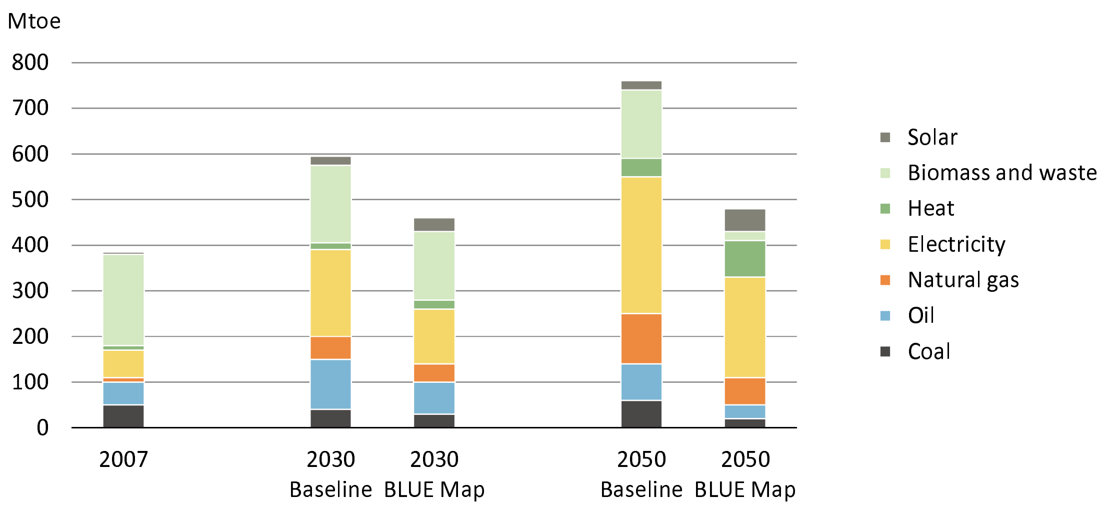


Figure 2.1 Energy Consumption of Chinese Building Sector (ETP 2010)

An essential concept employed in most energy (emission) models is process engineering estimates of the cost and efficiency of various energy conversion processes. For example, representations of one or more electric generation technologies that use fossil fuel combustion to run a turbine generator. Such a system generally has an energy conversion efficiency of 35-40%. Such characterizations are common in process analyses employed in applied mathematical programming and they are used in some models in precisely this way. (J. Weyant, 1999)

Process engineering is widely used to model primary energy conversion owing to the large scale and homogeneous design of the facilities involved approach is increasingly being used to analyze energy demand technologies. By representing demand in terms of end-use energy services, such models include representations of alternative technologies that can be used to satisfy those end-use demands. These technologies can have different costs, conversion efficiencies and employ different input fuels. Thus different levels of home insulation and competition between gas combustion and electric heat-pumps can be explicitly considered, leading many to refer to this approach as a "bottom up" approach to energy demand modeling, as contrasted with the "top down" approach employed in many aggregate economic analyses. The advantages of the increased technological detail included in end-use energy modeling must be balanced against the increased data requirements and lack of behavioral response estimates at the appropriate level.

2.2 Efficiency Policies in the Chinese Residential Sector

2.2.1 Residential Energy Consumption in China

CO_2 emission from China has been increasing rapidly in recent years. Since year 2006, China has become the largest CO_2 emitter in the world (Figure 2.2). The residential building sector accounts for about 15% of the total energy consumption in China. Since 1990, the consumption of coal and biomass has been decreasing in Chinese households while the consumption of electricity, district heating, natural gas and petroleum products has been growing rapidly. Part of the growth in electricity, gas, heat and oil products is due to the increasing urban population and the improved standards of living that are being driven by rapid economic growth. Between 1990 and 2006, the urban population increased from 302 million to 577 million (91%), and its share of all energy use increased from 26% to 45%.

China covers a number of very diverse climate regions. As a result, energy consumption levels and patterns vary widely across the country. Regions in the north-east have significant heating loads, those in the center have cold winters and warm summers, and those in the south-east have only very modest heating requirements. Energy consumption by end-use is shown in Figure 2.3. In the residential sector, space and water heating and cooking dominate. The rapid growth in electric appliances and applications means that the electrical end-uses share of the total is growing quickly, albeit from a low base. The potential growth in demand for cooling and appliances is particularly high.

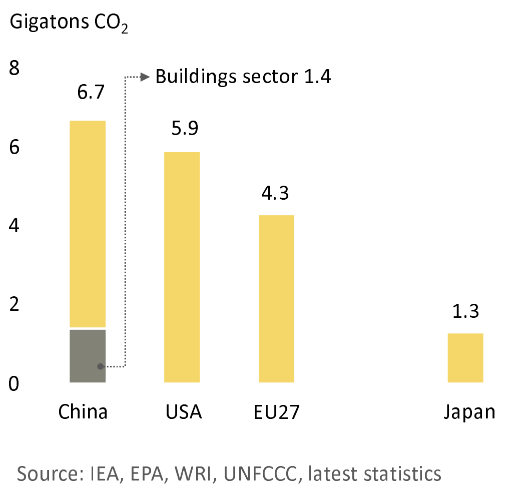


Figure 2.2 Ranking of national CO_2 emission

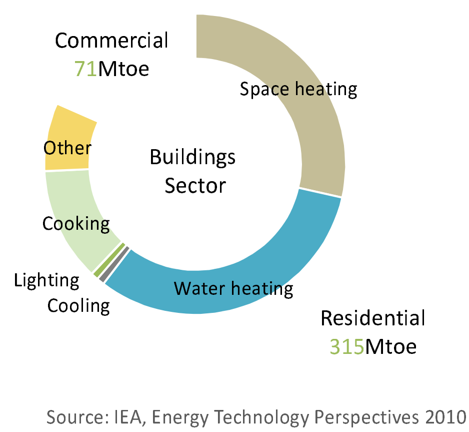


Figure 2.3 Energy consumption by end-use

2.2.2 Effective efficiency policies in the future

China has experienced rapid growth in energy demand in the buildings sector in recent years, particularly for higher-quality fuels. This rapid growth is driven by increased incomes and urbanization. The challenge this poses for energy and environmental systems is an area of increasing policy activity in China.

Energy efficiency in the buildings sector has been an emerging priority since the 1980s when China embarked on its large-scale urban construction effort. In 2005 the Chinese Ministry of Construction publishes a new civilian buildings energy conservation administration rule (IEA, Policies and Measures Database). It strengthens civil building energy conservation management, increase energy utilization efficiency, improve room inner heat environment. It replaces the old administration rule issued in 1999 and has been put into enforcement since January 1, 2006.

Since June 2007, China has addressed the energy consumption of appliances by introducing labeling schemes and minimum energy performance standards (MEPs) for a wide range of appliances. The MEP for appliances continues to be tightened over time. The result of these policy efforts has been to improve energy efficiency and generally to lower life-cycle costs for consumers. Increasing policy efforts have had a significant impact on the outlook for energy consumption in the buildings sector. (IEA, 2010)

Also in 2007 the Chinese Ministry of Construction launched "Green building evaluation labeling method" to improve the environmental performance of buildings. Most recently, a revised Energy Conservation Law, released in October 2007, has sought to address the issue of energy efficiency in buildings.

2.3 System Analysis and Prediction Models of CO_2 Emission

2.3.1 Introduction of System Analysis

Systems analysis is the process of investigation of a system's operation with a view to changing it to new requirements or improving its current working. This method has special advantages when it is impossible or too dangerous to test the solution in the real world. That is the reason that system analysis has become a sufficient way of prediction research.

Systems Analysis supports decision-making by providing greater understanding of the contribution of individual components to the energy system as a whole, and the interaction of the components and their effects on the system. Analysis will be used to continually evaluate the alternatives for satisfying the functions and requirements of the future system.

2.3.2 TIMER Model

The TIMER model was developed by National Institute of Public Health and the Environment (RIVM) of the Netherlands. It is a system-dynamics model which simulates the global energy system at an intermediate level of aggregation. The model simulates the world on the basis of 17 regions. The main objectives of TIMER are to analyze the long-term dynamics of energy conservation and the transition to non-fossil fuels within an integrated modeling framework, and explore long-term trends for energy-related greenhouse gas emissions. TIMER is a simulation model; it does not optimize scenario results over a complete modeling period on the basis of perfect foresight. Instead, TIMER simulates year-to-year investment decisions based on a combination of bottom-up engineering information and specific rules on investment behavior, fuel substitution and technology (Vries, 2001).

As a complement of macro-economic models, the TIMER model gives bottom-up process and system insights. The main features of the model are:

- activity-related demand for 2 energy source in 5 sectors, incorporating structural (economic) change due to inter- and intra-sectoral shifts;
- autonomous and price-induced changes in energy-intensity, covering what is referred to as energy conservation, energy efficiency improvement or energy productivity increase;
- fossil fuel exploration and exploitation, including the dynamics of depletion and learning;
- market penetrating of biomass derived and electric power generation;
- trade of fossil fuels and biofuels between the 17 world regions.

The model consists of 6 sub-models (Figure 2.4). Important components of the various sub models are: price-driven fuel and technology substitution processes, cost decrease as a consequence of accumulated production ('learning-by-doing'), resource depletion as a function of cumulated use (long-term supply cost curves) and price-driven fuel trade.

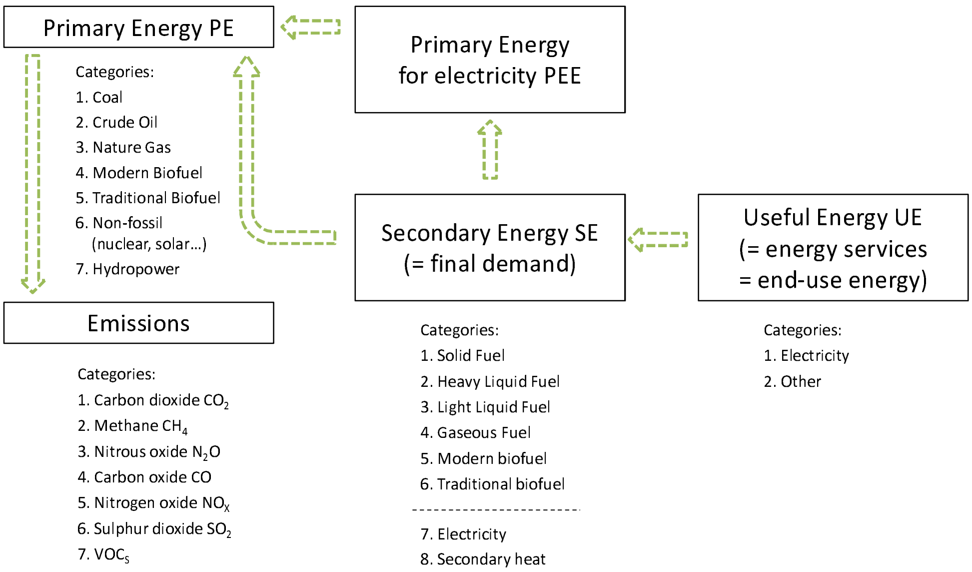


Figure 2.4 Overview of the TIMER model's sub-models

In the Energy Demand model the demand for final energy is modeled as a function of changes in population, economic activity and energy efficiency improvement. The energy demand is calculated for five different sectors, and for eight different types of energy carriers. Next, the calculated demand for energy services/useful energy is first multiplied by the Autonomous Energy Efficiency Increase (AEEI) multiplier. The AEEI accounts for observed historical trends of decreasing energy intensity in most sectors, even with decreasing energy prices. The AEEI is assumed to decline exponentially to some lower bound and is linked to the turnover rate of sectoral capital stocks.

The Emissions model calculates the emissions into the atmosphere from energy- and industry-related processes. The model consists of two modules: the energy-emission- and the industry emission module. In each, time-dependent emission coefficients are applied on the primary energy use fluxes and industrial activity levels, representing technological improvements and end-of-pipe control techniques for several greenhouse gases.

Furthermore, a division has been made into five categories of model variables, each one with its distinct characteristics. This makes it easier to see which variables should be compared with historical data and which are to be estimated from expert literature and/or sensitivity analyses. This thorough data calibration system is a big feature of TIMER model. The adjustment of input parameters including exogenous drivers based either on historical facts or on assumptions ensures that the outputs of TIMER consist with historical statistics and estimates from other research. Figure 2.5 shows the well matched estimates results from TIMER and other 2 global energy models.

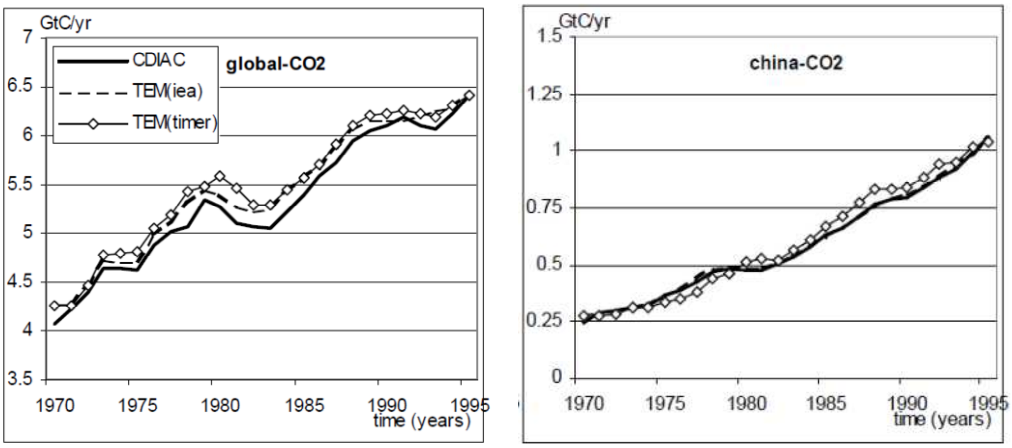


Figure 2.5 TIMER model's CO_2 emission estimates at global (left) and China (right) scales

2.3.3 EPPA (ver.4) Model

The MIT Emissions Predictions and Policy Analysis (EPPA) model is a recursive-dynamic multi-regional general equilibrium model of the world economy, which is built on the GTAP (Global Trade Analysis Project) dataset and additional data for the greenhouse gas (GHG) and urban gas emissions. Here it gives a general review of the latest version: EPPA4.

As a part of the MIT Integrated Global Systems Model (IGSM), EPPA belongs to a class of economic simulation models known as computable general equilibrium (CGE) models. CGE models represent the circular flow of goods and services in the economy, as illustrated in Figure 2.6. The key features of the model and the components required to link a model based on economic variables to the physical quantities (e.g., CO_2, energy consumption, land use) to an analysis of human-climate interaction (Paltsev, 2005).

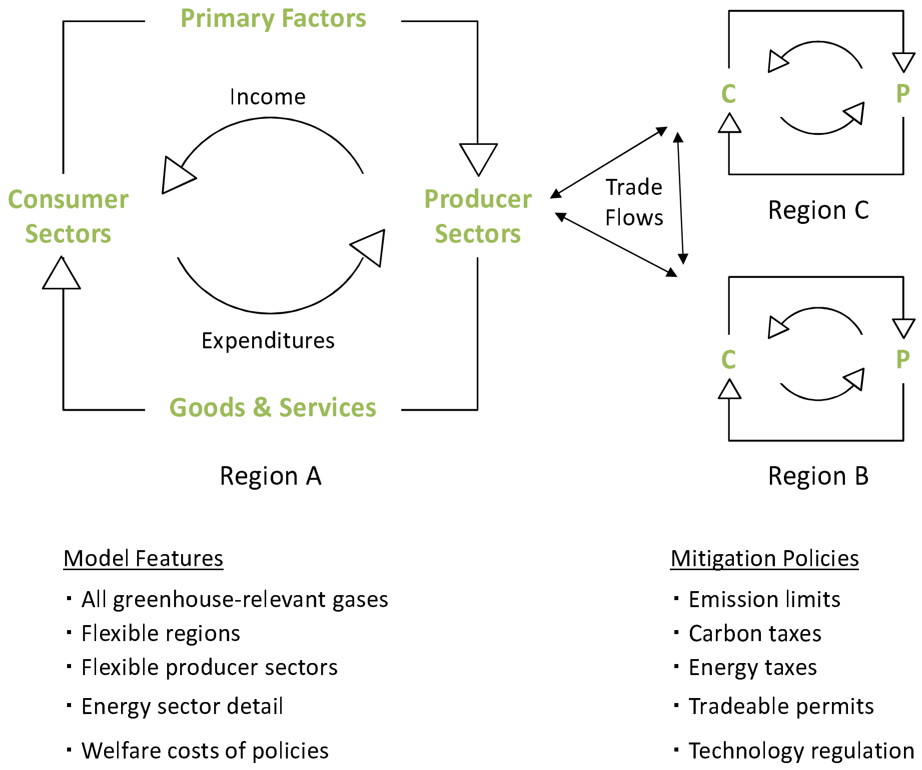


Figure 2.6 The circular flow of goods and resources in EPPA

As illustrated in Figure 2.6, EPPA also models trade flows for all goods among regions. Some goods (e.g., crude oil, emissions permits) are treated as perfect substitutes in global trade. For most goods, however, the model embodies the Armington convention widely used in modeling international trade whereby a domestically produced good is treated as a different commodity from an imported good produced by the same industry.

Another important aspect of CGE models is the degree to which they capture the dynamics of the economy through time, particularly their representation of savings-investment decisions. Other than the emission prediction, EPPA model also plots the relationship between imposed taxes on carbon and the levels of emissions reduction. This relationship is known as a marginal abatement cost curve (or MAC) and has been used to assess the impacts of emission trading and other policy questions (Morris, 2008).

2.3.4 Estimation Macro-model for Residential Energy Consumption

The "Estimation Macro-model for Residential Energy Consumption" was developed to evaluate the CO_2 emissions from Japanese residential sector exclusively. It is a bottom-up engineering model. Using a back-casting method, this model was able to operate a thorough analysis on households' energy consumption, and give various choices for CO_2 emissions deductions as well. Figure 2.7 is the flow chart of estimation process (Ikaga, 2005).

CO_2 emissions from houses vary significantly depending on factors such as the climate, family composition, changes in lifestyle, so, it is important to understand the energy consumption situation broken down by heating & cooling, hot-water supply, and others (uses for kitchens, home entertainment, housework, sanitary and lighting) for each prefecture and for each of seven family types ((1) households with an elderly single person only, (2) other households with a single member, (3) households with a elderly married couple only, (4) other households with a married couple, (5) households with parents and a child or children, (6) households with a single parent and a child or children, and (7) other households) in order to take proper measures.

The model was combined with low carbon scenarios from "Research project on establishing of methodology to evaluate middle to long term environmental policy option toward low carbon society in Japan". The 60% emission deduction scenario includes efficiency policies to improve household energy efficiency in a great level, such like Improvement of thermal insulation for new houses, Promotion of the purchase of heat pump water heaters to replace electric water heaters and Promotion of the purchase of the energy saving.

As the simulation outputs of the model, CO_2 emissions through 2050 could be illustrated to time transition graphs. Figure 2.8 shows the results graphics that are generated directly from the model. The emission abatement from each application was also quantitatively estimated.

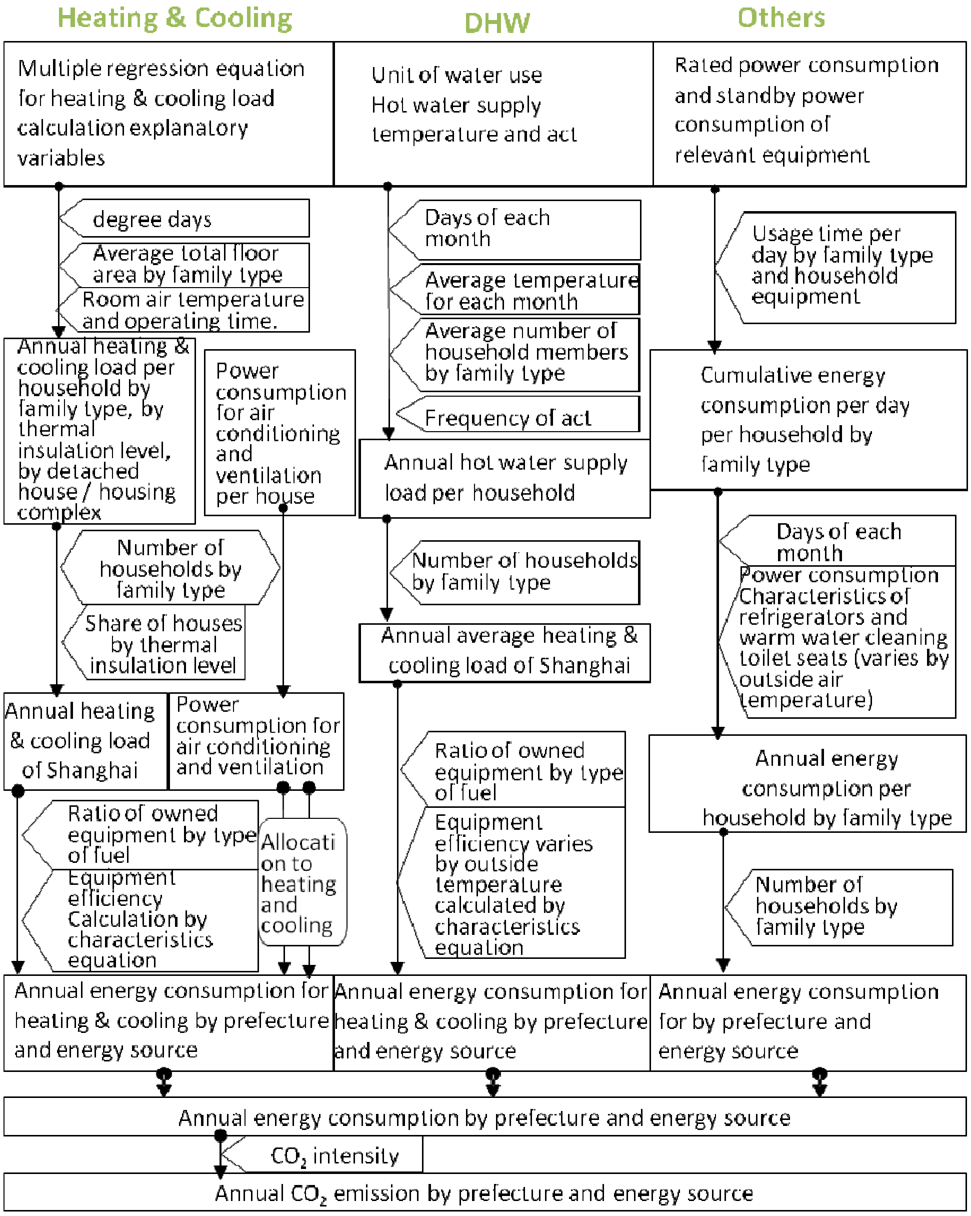


Figure 2.7 The simulation structure of the macro-model

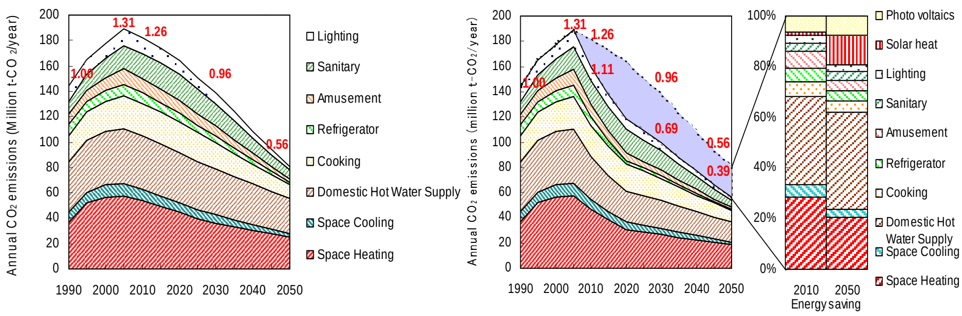


Figure 2.8 The simulation outputs of the macro-model

2.4 Marginal Abatement Cost

2.4.1 The Concept of MAC (Marginal Abatement Cost)

Policy makers in many countries around the world have agreed to substantially reduce carbon emissions over the coming years. Confronted with a situation of legally binding commitments, the question arises of how to reduce carbon emissions in a cost-efficient way. For this purpose, marginal abatement cost (MAC) curves, which contrast marginal abatement cost and total emission abatement, have been frequently used in the past to illustrate the economics of climate change mitigation and have contributed to decision making in the context of climate policy. The concept of carbon abatement curves has been applied since the early 1990s to illustrate the cost associated with carbon abatement. In recent years, the concept has become very popular with policy makers and is used not only in developed but also in developing countries. Policy makers now find themselves confronted with MAC curves that are derived in different ways (F. Kesicki, 2010).

2.4.2 Two Types of MACC: Expert-based and Model-derived

During the abatement assessment, a baseline with no CO_2 constraint has to be defined in order to assess the marginal abatement cost against this baseline development. A MAC curve allows one to analyse the cost of the last abated unit of CO_2 for a defined abatement level while obtaining insights into the total abatement costs through the integral of the abatement cost curve. According to the underlying methodology, MAC curves can be divided into expert-based and model-derived curves. Typical graphical presentations of both types are given in Figure 2.9.

Expert-based approaches, sometimes also called technology cost curves, are built upon assumptions developed by experts for the baseline development of CO_2 emissions, the emission reduction

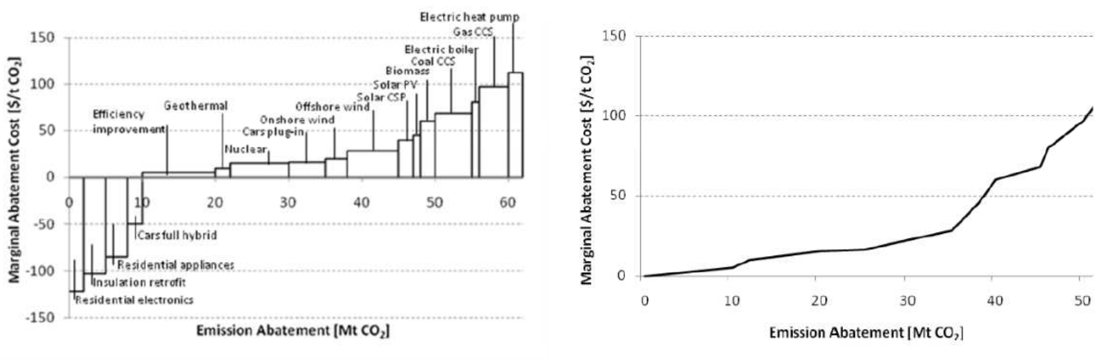


Figure 2.9 Examples for expert-based (left) and model-derived (right) MAC curves

potential and the corresponding cost of single measures (including new technologies, fuel switches and efficiency improvements). Subsequently, the measures are explicitly ranked from cheapest to most expensive to represent the costs of achieving incremental levels of emissions reduction. A wild know example of expert-based MAC curve is published by McKinsey & Company (see Figure 2.9, left).

Abatement curves based on a societal perspective use a lower discount rate of e.g. 3.5% to reflect society's preference over time, while curves from a private perspective integrate subsidies, taxes and higher interest rates to measure the costs faced by private individuals when making investment decisions.

Another widespread approach to MAC curves is to derive the cost and potential for emission mitigation from model runs. A number of energy models have been used in this way using a range of techniques. The most common way is to distinguish models into economy-orientated top-down models and engineering-orientated bottom-up models. In both cases, abatement curves are generated by summarizing the CO_2 price resulting either from runs with different strict emission limits or from the emissions resulting from different CO_2 prices. This focus on absolute emission means that the presentation of a model-derived abatement curve does generally not contain any technological detail.

A last point concerns the insufficient representation of cost-independent market distortions in energy models. Since both energy model types assume rational agents with cost-efficient behavior, such distortions are not possible to represent in optimization models. The result is that these models do not show negative abatement costs. Nevertheless, in bottom-up models there are opportunities to incorporate higher hurdle rates and upper limits for the use of mitigation technologies to represent problems connected to high upfront investment costs and other distortions with regard to no-regret measures.

Table 2.1 Strengths and weakness of expert-based MAC Curves and model-derived MACC (F. Kesicki, 2010)

Expert-based MAC Curves		Model-derived MAC Curves	
STRENGTHS	WEAKNESS	STRENGTHS	WEAKNESS
▪ Extensive technological detail ▪ Possibility of taking into account technology specific market distortions ▪ Marginal abatement cost definition can change according to the chosen perspective ▪ Easy understanding of technology-specific abatement curves	▪ No integration of behavioral factors ▪ No integration of interactions and dependencies between mitigation measures ▪ Possibility of inconsistent baseline emissions ▪ No representation of intertemporal interactions ▪ Limited representation of uncertainty ▪ In some cases, limited to one economic sector without the possibility to accumulate abatement curves across sectors ▪ No representation of macroeconomic feedbacks ▪ Simplified technological cost structure	Bottom-up	Bottom-up
		▪ Model explicitly maps energy technologies in detail	▪ No macroeconomic feedbacks ▪ Direct cost in the energy sector ▪ Risk of penny-switching ▪ No consideration of rebound effect
		Top-down	Top-down
		▪ Macroeconomic feedbacks considered ▪ Macro-economic cost considered	▪ Model lacks technological detail ▪ Possible unrealistic physical implications
		Both	Both
		▪ Interactions between measures included ▪ Consistent baseline emission pathway ▪ Intertemporal interactions incorporated ▪ Possibility to represent uncertainty ▪ Incorporation of behavioral factors ▪ Comparably quick generation	▪ No technological detail in representation of MAC curve ▪ Assumption of a rational agent, disregarding market distortions

2.4.3 Chinese MACC

In February 2009 McKinsey & Company published "China's green revolution" report which gave an in-depth analysis of China's environmental sustainability in the future (McKinsey & Co., 2009). In this report, over 200 efficiency and abatement technologies have been quantitatively analyzed with a special focus on 5 sectors: residential and commercial buildings and appliances; transportation; emission intensive industries; and agriculture & forestry. In additional, with consider of capital and maintenance costs (excluding taxes, tariffs and subsides), the report also provided marginal abatement cost curve in each sector associated with switching to new technologies.

Specifically in buildings and appliances sector, the report pointed out that the 2 decades from 2010 to 2030 will prove critical for reducing emissions from buildings & appliances and improving sustainability. These two decades will see the peak of building-space expansion and a massive rise in energy consumption by Chinese consumers in homes and offices. At the same time, there is an opportunity for China to set new precedents in building design, construction and energy consumption. From the cost side, abatement technique in the building sector saw the lowest cost overall. It was estimated that about 70 percent of the abatement potential has a negative cost. The biggest abatement opportunities are efficient building envelopes, efficient HVAC systems, and energy-efficient lighting.

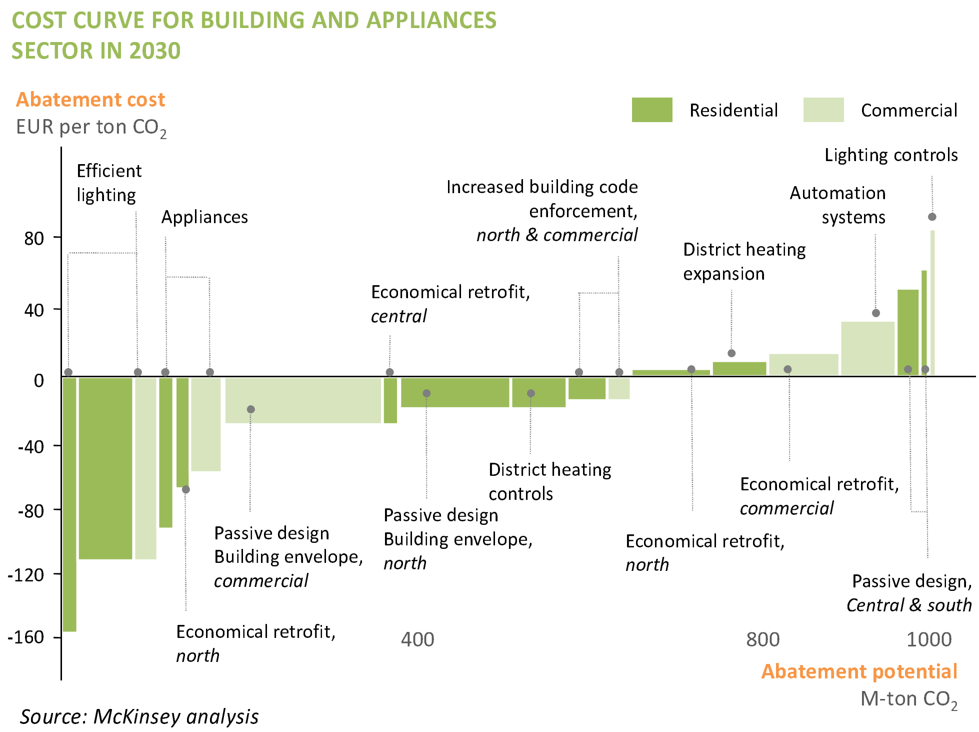


Figure 2.10 McKinsey & Company projected MACC of Chinese building sector

2.5 Summary

In 2005, global atmospheric concentrations of CO_2 were 35% higher than they were before the Industrial Revolution. Regarding the mitigation and adaptation of the global warming issue, system modeling has become a popular research method.

This chapter introduced the basic approach of 3 popular energy (emission) models: the TIMER model from RIVM of the Netherlands, the EPPA model from MIT, and estimation macro-model for residential energy consumption from Japan. The modeling methods of both bottom-up and top-down were thoroughly examined.

Furthermore, the concept of marginal abatement cost curve (MACC) has been presented in this chapter. A MACC allows one to analyze the cost of the last abated unit of CO_2 for a defined abatement level while obtaining insights into the total abatement costs through the integral of the abatement cost curve. It highly efficient in terms of policy assessment research and has been used as a major analyze method in this study.

Chapter 3

Introduction of the Evaluation Model

"A model should be made as simple as possible, but no simpler". (Einstein's razor)

CONTENTS

A macro simulation model is developed in this study to conduct all the future prediction and evaluations. The applied model consists of 3 sub-models. First the CO_2 emission sub-model simulates the demand for final energy on the parameter inputs of futures trends. Then the efficiency scenarios sub-model provides 3 future scenarios to predict the growth and reduction potential of CO_2 emissions. The third sub-model marginal abatement curve (MAC) sub-model estimates the necessary cost and financial benefits from each proposed policy and produces MAC curves. This chapter focuses on describing the specific structure and details of the simulation model, as well as the estimation process and relationship between each sub-model.

3.1 Overview of the Evaluation Model

In this research we first developed a macro-model to estimate CO_2 emissions and marginal abatement cost. The model is a combination of bottom-up engineering information and efficiency scenario settings. It consists of 3 sub-models, CO_2 emission sub-model, efficiency scenarios sub-model, and Marginal Abatement Cost (MAC) sub-model. Figure 3.1 indicates the general modeling process and main exogenous inputs. The model's 2 major outputs: CO_2 reduction potential and marginal abatement cost can be used to support decision-making when setting appropriate CO2 emission reduction goals as well as selecting efficient efficiency policies.

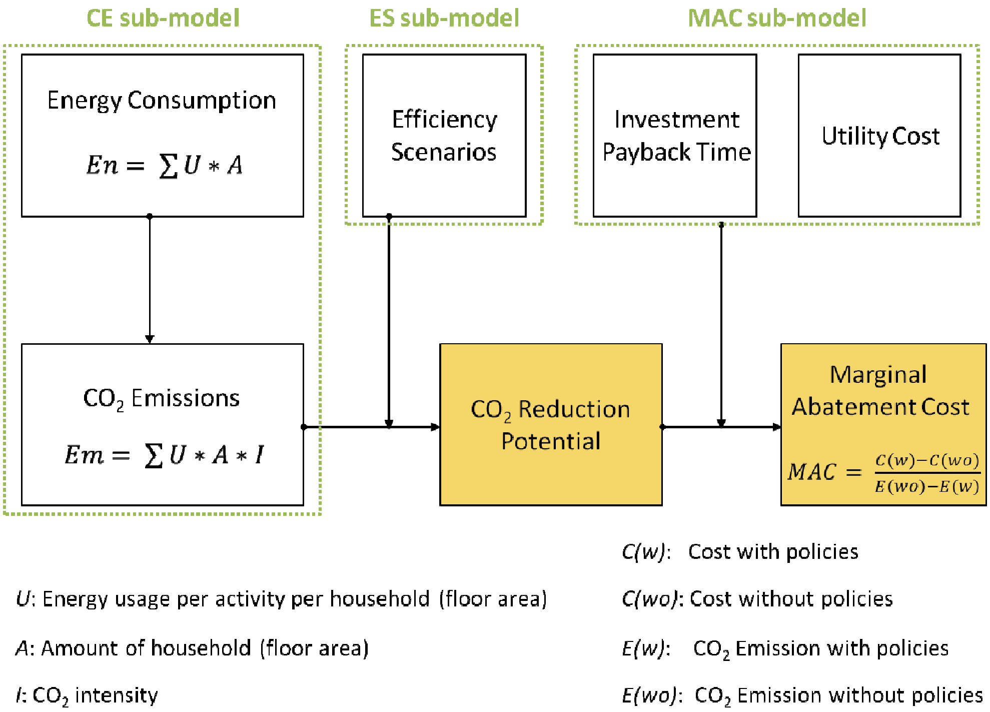


Figure 3.1 Modeling process of the evaluation model

First CE sub-model evaluates energy consumption and CO_2 emissions from residential sector of each Chinese district. Then ES sub-model provides several future options of efficiency policies to estimate CO_2 reduction potentials. Included in the third sub-model that are investment cost and payback time of efficiency policies, and energy price of each energy source, which ensure the model to calculate marginal abatement costs of efficiency polices.

3.2 CO_2 Emission (CE) Sub-model Description

The CO_2 emission sub-model is a 3-step simulation model based on bottom-up approach. First it simulates the demand for final energy on the parameter inputs of futures trends in a variety of factors, of which the most important are changes of living standard, technological progress, and assumptions with regard to lifestyles.

An overview of the CO_2 emission model is given in Figure 3.2.

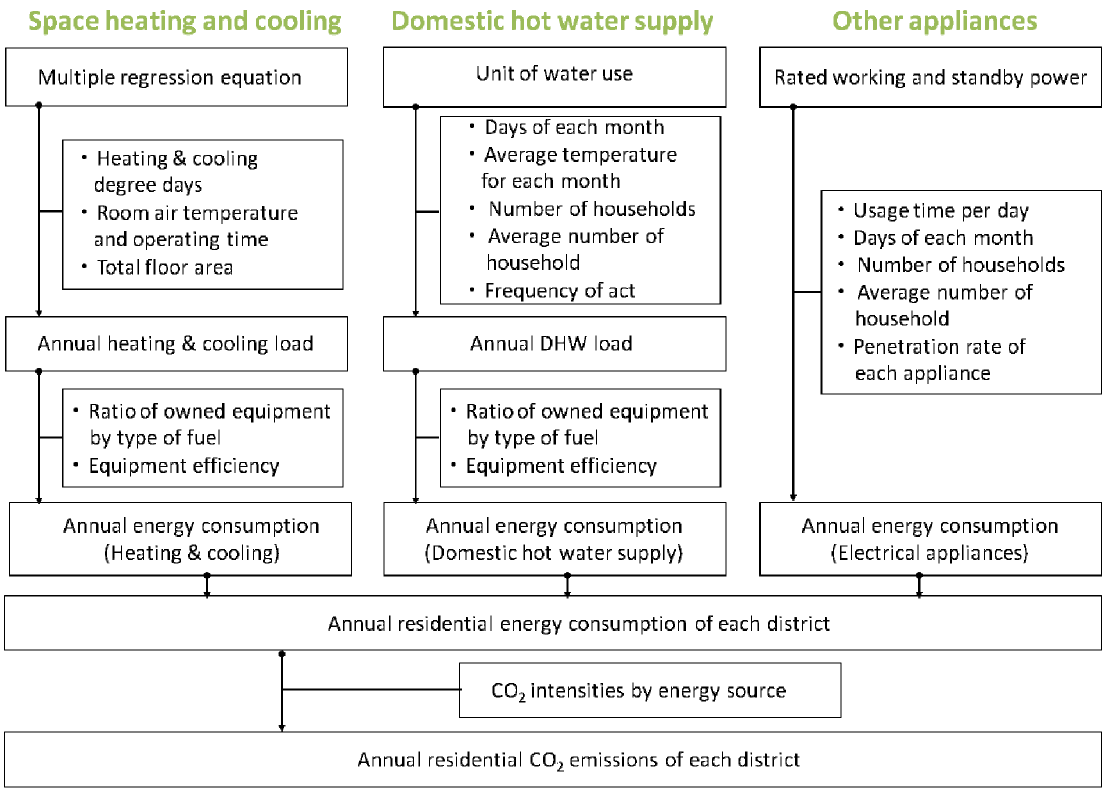


Figure 3.2 Flow chart of CO_2 emission sub-model

It is a macro simulation model that estimates the changes in energy consumption and CO_2 emissions by different family types, applications and energy sources every year. Estimation methods are shown as below.

Space heating/cooling: Annual load per household calculated by a multiple regression equation (equation 3.1) for heating & cooling load. The annual total load of each district is calculated by multiplying the amount of total floor areas.

$$L_{Ht,Cl} = c_0 + c_1 \times DD + c_2 \times U + c_3 \times T + c_4 \times H \quad (3.1)$$

Where $L_{Ht,Cl}$ is load of heating or cooling, $c_0 \sim c_4$ are the coefficients of the regression equation. *DD* represents degree day (Appendix 11), *U* represents the over overall heat transmission coefficient (W/m^2K), *T* represents room temperature, and *H* represents operation hours. The value of $c_0 \sim c_4$ for each climatic area refer to the Japanese estimation model (Ikaga, 2005), which are listed in Table

Table 3.1 Coefficients of heating and cooling load

	Heating					Cooling				
	c_0	c_1	c_2	c_3	c_4	c_0	c_1	c_2	c_3	c_4
Severe cold	-1147.3	0.1	327.2	24.9	1.0	146.1	0.6	-0.2	-6.2	1.5
Cold	-660.1	0.1	122.0	16.8	2.6	225.1	0.4	-0.2	-9.2	2.0
HSCW	-503.0	0.1	88.9	15.0	2.0	463.3	0.4	1.4	-18.9	3.3
Temperate	-421.4	0.1	67.3	13.3	1.6	643.5	0.4	1.7	-26.5	4.3
HSWW	-355.1	0.1	48.5	11.7	1.4	904.9	0.2	6.2	-34.9	6.4

HSCW: Hot Summer Cold Winter HSWW: Hot Summer Warm Winter

Domestic hot water (DHW) supply: The DHW loads of face washing, cooking, and shower are calculated respectively using equation 3.2.

$$L_{DHW} = c\rho V (T_s - T_t) \quad (3.2)$$

Where L_{DHW} is load of domestic hot water (DHW) supply, *c* is the specific heat coefficient of water (kJ/kg°C), ρ is water density (kg/L), *V* is the usage of domestic hot water, *Ts* is supply temperature of DHW (°C), and *Tt* is the average temperature of tap water (°C). The supply temperature and water usage of three hot water usages: face washing, cooking and shower are set up by each season as table 3.2 (SCHEDULE Ver. 2.0, 2000).

Table 3.2 Supply temperature and usage of domestic hot water

	Dec.-Feb.		Jun.-Aug.		Others	
	Ts (°C)	*V* (L)	*Ts* (°C)	*V* (L)	*Ts* (°C)	*V* (L)
Face washing	38.0	13.9	39.0	10.5	39.3	12.9
Cooking	39.0	14.6	39.7	12.0	39.7	12.7
Shower	39.0	21.2	37.7	36.0	38.3	25.6

The temperature of the tap water various from season to season, and is also influenced by the geographies. *Tt* of each different climatic area is calculated by equation 3.3 (Ikaga, 2005).

$$T_t = aT + b$$
(3.3)

Where *T* is the regional average temperature (see appendix 11), *a* and *b* are both coefficients for tap water temperature estimation (table 3.2).

Table 3.3 Coefficients of tap water temperature estimation

	a	b
Severe cold	0.6639	3.466
Cold	0.6054	4.515
HSCW	0.8075	3.342
Temperate	0.6921	7.167
HSWW	0.9223	2.907

HSCW: Hot Summer Cold Winter HSWW: Hot Summer Warm Winter

3.3 Efficiency Scenarios (ES) Sub-model Description

In this paper 3 efficiency scenarios are proposed for the future prediction: Frozen Technology Scenario, Reference Scenario, and Abatement Scenario. The concept and mechanism of the efficiency scenarios are illustrated in Figure 3.3.

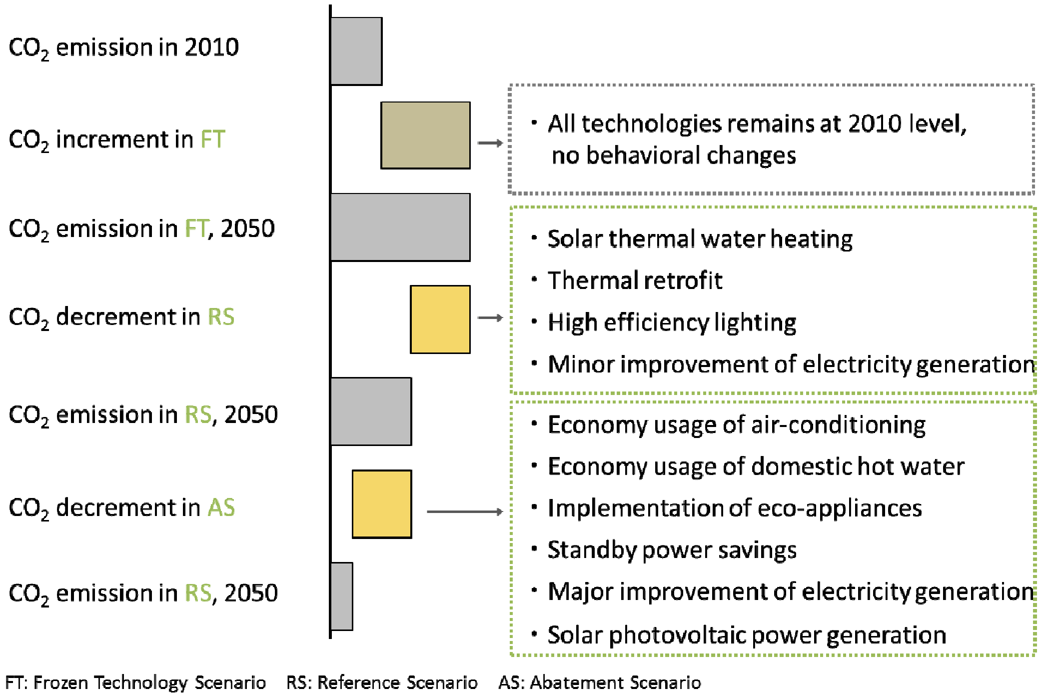


Figure 3.3 Flow chart of the efficiency scenarios sub-model

3.3.1 Frozen Technology Scenario (FT)

In the frozen technology scenario (FT), it is assumed that all technologies including electricity CO_2 intensity (Table 3.4) stay at 2010 level and no change in lifestyle neither. This scenario is set to estimate how CO_2 emission will expand if no action is taken through the coming 40 years.

3.3.2 Reference Scenario (RS)

The reference scenario (RS) includes 4 efficiency policies that were plotted by the Chinese government.

<u>Thermal Retrofit</u>

In 2005 the Chinese Ministry of Construction publishes a new civilian buildings energy conservation administration rule (IEA, Policies and Measures Database). It strengthens civil building energy conservation management, increase energy utilization efficiency, improve room inner heat environment. It replaces the old administration rule issued in 1999 and has been effective since January 1, 2006.

Lighting Efficiency

In April 2008 the Chinese Ministry of Finance announced the efficient light bulb subsidy program (IEA, Policies and Measures Database). As part of a plan to phase out incandescent lighting, the Ministry of Finance announced the first stage of the plan, to subsidies 50 million low-energy bulbs onto the market. Subsidies will be indirect, with efficient bulbs cold to consumers at a discount and companies reimbursed by the government for the shortfall. Individual shoppers will pay half of the price agreed by manufacturers and the government. In July 2012 the State Council of China issued the first national plan for public services. In this plan the government announced to subsidy 350 million USD for promoting LED and other efficient light bulbs.

Solar Thermal

Renewable energy will also be playing an important role in the government-plotted plan. In January 2008, Shandong Province announced implementation of its One Million Rooftops Sunshine Plan, designed to stimulate the integration of various renewable energy sources into building construction (IEA policy database). The Plan targets use of solar power and geothermal power into buildings. Following this, compulsory regulations went into effect in the cities of Yantai and Jinan, for the integration of solar energy in the construction and design of certain buildings. Since 2011, Beijing has made it obligational for newly erected apartments to have solar heating systems. National widely, the Chinese 12th Five-Year Guideline established a growth target for the solar thermal utilization that in the coming 5 years (2011-2015) solar water heater should be used by 30% of all households.

The average amount of heat energy produced by a flat plate solar collector during a year has been calculated by formula 3.4.

$$Q = A \cdot E \cdot \eta \qquad (3.4)$$

Where *Q* is the average amount of heat energy, produced by a solar collector during a year, *A* is the solar collector area (2 m^2/household), *E* is the average amount of heat energy received by 1 m^2 of a solar collector during a year, and η is the efficiency of the collector. Here the efficiency η was considered as 40% referring to Solar System Development Association of Japan.

Electricity Generation

National Development and Reform Commission of China launched an energy efficiency transition plan in 2004 (NDRC, 2004). The plan sets up several technology indices for the improvement of energy efficiency, which includes electricity CO_2 intensity of coal fired power generation. According to the plan in reference scenario the electricity CO_2 intensity of coal fired power generation is set to be reduced to 0.84 kg-CO_2/kWh by 2020 (Table 3.4).

Such policies involved with government plan have been included in RS. However, behavioral changes of the residents are not included in the scenario. The RS can be seen as a baseline assessment of CO_2 emissions in the future. The objective of this scenario is to estimate reduction potential of government-plotted policies.

3.3.3 Abatement Scenario (AS)

Low-Carbon policies in the abatement scenario (AS) includes all the policies that adopted in reference scenario, and adds up economy usage of air-conditioning and DHW, implementation of eco-appliances, standby power savings, and a major improvement of electric generation.

Economy Lifestyle

This part of the Low-Carbon policies takes into account of efforts from the household side. Specifically such energy saving lifestyles include lowing (upping) the room temperature during winter (summer), shortening operating hours of air-conditioning, reducing standby power of household appliances, and using tap water for face washing and cooking during summer.

The energy saved by reducing usage of air-conditioning and hot water supply could be calculated by formula 3.1 and 3.2, respectively. Energy saved by cutting down the standby power could be calculated by usage information listed in table 4.2.

Solar Photovoltaic

The industry of photovoltaic solar energy generation in China grows fast in recent year. China has over 400 photovoltaic companies. In 2007 China produced 1.7 GW of solar panel capacity, nearly half of the world production of 3.8 GW, although 99% was exported. As of 2011, about 3.1 GW of photovoltaic contribute towards power generation in China (Biella, 2008). However, the amount of electricity generated with solar power within China itself was up until 2010 comparatively small: about 0.1% of total capacity.

In 2009 the Chinese Ministry of Finance launched the Golden Sun Program to move the national solar photovoltaic industry forward. The program provides subsidies to grid connected and off-grid solar PV power generation projects and calls for 500 MW of installed PV capacity by 2012 China-wide. Subsidy schemes have been designed both at the national and provincial levels and apply to 2011. In June 2011, the Chinese Ministry of Finance adjusted the solar PV subsidy framework under the Golden Sun program. Instead of subsidizing 50% of the cost of installation, transmission and distribution of generated electricity in grid-connected PV projects, the new rule includes a fixed tariff. Polysilicon-based modules will receive a subsidy of 9 RMB /W (1.40 USD) and thin-film modules of 8 RMB/W (1.24 USD).

At the moment the subsidies only cover projects like large scale power plant and rural electrification, PV panel installation in urban households are not included. However, it is most likely that PV technology will be penetrated into urban households as an alternative energy resource. Due to the lack of official plan, in abatement scenario a 0.5 kW capacity of PV panel is assumed to be installed in one household, and penetration rates are set as 1% till 2020 and 2% till 2050.

The electricity production from a photovoltaic module, P_{pv}, can be expressed as formula 3.5.

$$P_{pv} = P_{\max} \cdot \frac{I_s}{I_{STC}} \cdot \gamma \qquad (3.5)$$

Where p_{max} is the Installed capacity (0.5 kW/household), I_s is anural solar radiation (kWh/m^2), I_{STC} is radiation at standard conditions (1kW/m^2), and γ is loss coefficient for module efficiency (affected by temperature, shading, etc.). During the calculation loss coefficient γ is considered as 0.58 (Nishizawa, 1998).

Electricity Generation

Although the Chinese government has not announced any reduction plan for post 2020 period, electricity generation efficiency has drawn attention in many developed countries such like Japan. Taking the reduction target in Japan as reference, in abatement scenario electricity CO_2 intensity is set to be reduced to 0.62 kg-CO_2/kWh by 2020 from the current level of 0.95, and 0.41 kg-CO_2/kWh by 2050 (Table 3.4).

Table 3.4 Electricity CO_2 intensities' projection in 3 scenarios

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
FT	1.03	1.00	0.95	0.90	0.84	0.84	0.84	0.84	0.84	0.84	0.84
RS	1.03	1.00	0.95	0.90	0.84	0.84	0.84	0.84	0.84	0.84	0.84
AS	1.03	1.00	0.95	0.79	0.62	0.59	0.55	0.52	0.48	0.45	0.41

(Unit: kg-CO_2/kWh)

Compare to RS, AS takes energy saving lifestyles, efficient appliances and a significant improvement of electric power generation into account. This scenario intends to create an optimal case of low carbon future, and evaluate the maximum deduction potential of CO_2 emission.

3.4 Marginal Abatement Cost (MAC) sub-model Description

The estimation process of MAC sub-model is based on outputs from the other 2 sub-models. First the other 2 sub-models estimate the energy consumption decrement of each efficiency policy. For equipment improvement policies the information of investment cost, payback time and energy bills are given to calculate the marginal abatement cost. On the other hand for behavioral changes policies the conserved energy cost is calculated by each energy source. An overview of the marginal abatement cost sub-model is given in Figure 3.4.

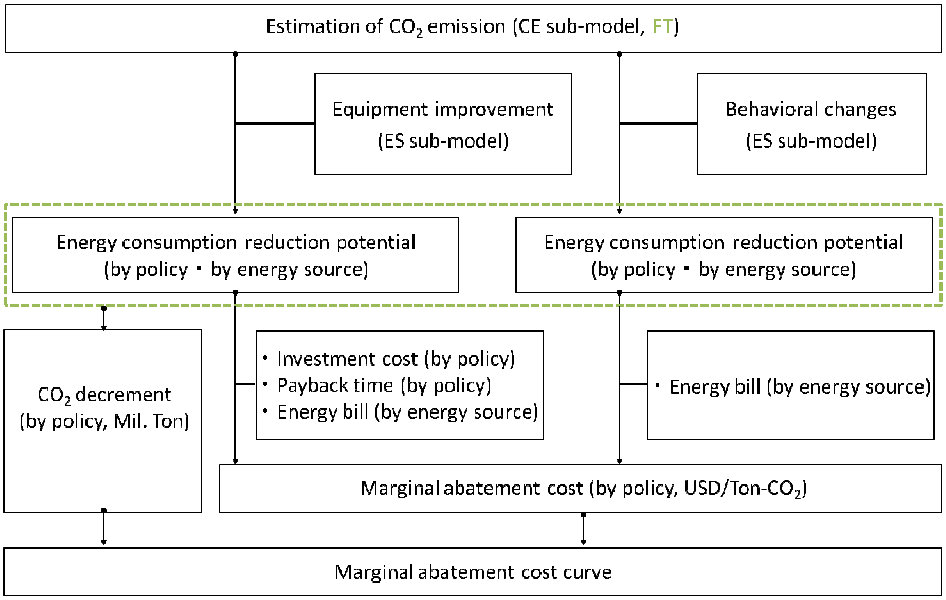


Figure 3.4 Flow chart of MAC sub-model

The overall concept of MAC could be explained by equation 3.6 (McKinsey&Co., 2009)

$$MAC = (C(w) - C(wo))/(E(w) - E(wo)) \quad (3.6)$$

Where *MAC* represents marginal abatement cost (USD/Ton), *C(wo)* is the total cost (USD) without penetration of efficiency policies, *C(w)* is the total cost (USD) with penetration of efficiency policies, *E(wo)* is the total CO_2 emission (Ton) without penetration of efficiency policies, and *E(w)* is the total CO_2 emission (Ton) with penetration of efficiency policies.

In this research the present costs (prices) are used to estimate the future, such as year 2050' costs (prices). Thus social discount rate has been considered in the calculation. Social discount rate could also be seen as an annual rate of interest, and it is often stated as percentages. Here the future value is estimated by setting the discount rate as 4% (NIES, 2009).

The relationship between present value and future value could be described by equation 3.7.

$$FV = PV(1+i)^n \tag{3.7}$$

Where *FV* represents future value (USD), *PV* represents present value (USD), *i* is the social discount rate and *n* is time between future year and present year.

3.4.1 MAC of Behavioral Changes Policies

The MAC of efficient heating in the northern cold area is calculated by equation 3.8.

$$MAC_{CH} = PR_{CH} \cdot (1+r_E)^t \cdot SQ_{CH} \cdot PE_{CH} \cdot (En(w)/En(wo)-1)/(E(wo)-E(w)) \tag{3.8}$$

Where MAC_{CH} represents MAC (USD/Ton) of efficient heating policy, PR_{CH} is the monthly cost (USD/sqm・month) of central heating, r_E is the average social discount rate of energy price, *t* is the time between base year (2012) and result year, SQ_{CH} is the central heated area (sqm), PE_{CH} is the central heating period, *En(wo)* is the anural energy consumption (PJ) for central heating without penetration of efficiency policies, and *En(w)* is the anural energy consumption (PJ) for central heating with penetration of efficiency. The social discount of energy price normally is different from source to source. To simplify the estimating process here r_E is set as 5% refer to the discount rate of electricity price (IEA, 2010).

The MACs of other policies in the rest area are calculated by equation 3.9.

$$MAC_{ot} = (\sum PR_i \cdot En(w)_i \cdot S_i - \sum PR_i \cdot En(wo)_i \cdot S_i) \cdot (1+r_E)^t /(E(wo)-E(w)) \tag{3.9}$$

Where MAC_{ot} represents MACs (USD/Ton) of efficiency polices (besides efficient heating), PR_i is the price (USD) of each energy source, $En(wo)_i$ is the anural energy consumption of each energy source without penetration of efficiency policies, $En(w)_i$ is the anural energy consumption of each energy source with penetration of efficiency, and S_i is the energy share of electricity and city gas respectively.

3.4.2 MAC of Equipment Improvement Policies

The MACs of equipment improvement policies is calculated by equation 3.10 with consideration of a 4% average social discount.

$$MAC_{EI} = (IC_i \cdot (1 + r_I)^t / PT_i + EC(wo) - EC(w)) / (E(wo) - E(w)) \tag{3.10}$$

Where MAC_{EI} represents MACs (USD/Ton) of equipment improvement policies, IC_i is the initial investment cost (USD) of each technology, r_I is the 4% average social discount rate (NIES, 2009), PT_i is payback time (year) of each technology, *EC(wo)* is the anural energy cost (USD) without penetration of efficiency policies, and *EC(w)* is the anural energy cost (USD) with penetration of efficiency.

Here IC_i and PT_i refer to previous study of National Institute for Environmental Studies (NIES, 2009). During the calculation, Chinese manufacture price was assumed to be at 4% of Japanese price (U. S. Department of Labor, 2011).

The anural energy cost is calculated the by energy price and reductions (see 3.3.1). As explained before, MAC sub-model works closely with CE sub-mode, thus here energy consumption *EC(wo)*, *EC(w)*, CO_2 emissions *E(wo)*, *E(w)* refer to outputs of CE sub-model.

3.5 Summary

This chapter mainly presented the structure of the evaluation model, which is a combination of bottom-up engineering information and efficiency scenario settings. It consists of 3 sub-models, CO_2 emission sub-model, efficiency scenarios sub-model, and Marginal Abatement Cost (MAC) sub-model.

The CO_2 emission sub-model is a 3-step simulation model based on bottom-up approach. First it simulates the demand for final energy on the parameter inputs of futures trends in a variety of factors, of which the most important are changes of living standard, technological progress, and assumptions with regard to lifestyles.

The efficiency scenarios sub-model has 3 future scenarios prepared for the energy consumption and CO_2 emission predictions: Frozen Technology Scenario, Reference Scenario, and Abatement Scenario. The FT scenario simply meant to estimate the future growth of CO_2 emission, while other 2 efficiency scenarios evaluate the reduction potential of implementing efficiency policies.

Last but not least the MAC sub-model estimated the necessary cost and financial benefits from each policy, in order to eventually produce a MAC curve.

The model's main outputs – CO_2 reduction potential and marginal abatement cost can be used to support decision-making when setting appropriate CO_2 emission reduction goals as well as selecting efficient efficiency policies.

Chapter 4

Database of the Evaluation Model

"God is in the details." (Ludwig Mies van der Rohe)

CONTENTS

The future prediction of CO_2 emission and marginal abatement cost involves big amounts of data, such like household numbers, floor areas, and penetration rate of appliances. This chapter explains how the database is constructed and which source is used to collect all the needed data.

4.1 Household Database

4.1.1 Projection of Household

The number of people living in China at a given time will only change when one of the following three events takes place: a birth in china, the death of someone living in China, and a person migrating into or out of China. These components of population change are usually measured by observable rates: the fertility rate, the mortality rate and the migration rate, respectively. Considering such components cohort-components method is applies for population projection. (Chen, 2009)

Specifically population in 2010 is used as an initial population to be grouped into cohorts defined by age and sex, and the projection proceeds by updating the population of every 5 years age-specific group for both male and female. In this projection, the fertility rate of each district refers to Chinese year book 2009, and the mortality rates of age- and sex-specific group refer to Chinese population year book 2002. The component of migration has not been considered in the projection. Each cohort survives forward to next age group according to the above components (Kurita, 2004). The cohort-component method of population projection is illustrated in Figure 4.2. The regional natality, mortality and household-owner-rate are listed in Table 4.1(China Population Statistics Yearbook, 2003).

Figure 4.1 shows the projected household number and size of Beijing. Due to the one-child policy the overall household number will increase slowly, and then start to drop from 2040. Persons per household will also decrease from the current level. It has been estimated that in year 2050 there will be averagely less than 3 persons in one household. Projections of all 31 districts are listed in Appendix 1 (household number) and Appendix 2 (person per household).

Figure 4.1 Projected household number (left) and household size (right) of Beijing

Table 4.1 The regional natality, mortality and household-owner-rate

	Natality (‰)
Heilongjiang	13.70
Inner Mongolia	17.53
Qinghai	26.58
Tibet	28.04
Xinjiang	29.29
Jilin	12.25
Liaoling	11.10
Beijing	14.76
Tianjin	15.20
Hebei	23.68
Shandong	21.43
Ningxia	26.34
Sichuan	16.76
Shaanxi	18.76
Shanxi	19.91
Gansu	24.40
Shanghai	15.83
Anhui	23.94
Henan	20.97
Jiangsu	17.49
Chongqing	18.13
Hunan	23.90
Zhejiang	18.72
Hubei	17.36
Jiangxi	25.41
Yunnan	22.95
Guizhou	25.00
Guangxi	25.96
Guangdong	21.58
Fujian	22.35
Hainan	26.85

Age	**Mortality** (‰)		**Household-owner-rate** (‰)	
	Male	**Female**	**Male**	**Female**
0-4	2.23	2.61	0.17	0.15
5-9	0.59	0.39	0.17	0.15
10-14	0.44	0.17	0.17	0.15
15-19	0.61	0.12	2.84	2.42
20-24	0.48	0.03	19.30	10.29
25-29	0.60	0.55	45.51	12.96
30-34	1.02	0.39	63.20	15.42
35-39	1.26	0.81	73.10	17.12
40-44	2.29	1.05	78.47	18.51
45-49	2.42	2.29	81.42	19.48
50-54	3.49	2.23	82.23	20.92
55-59	8.57	3.41	80.08	22.63
60-64	12.67	6.31	77.77	26.21
65-69	19.53	13.21	72.60	35.45
70-74	36.75	19.65	72.60	35.45
75-79	57.57	41.42	72.60	35.45
80-84	95.05	56.35	72.60	35.45
85-89	125.11	93.25	72.60	35.45
90-94	108.82	186.71	72.60	35.45
95+	108.82	186.71	72.60	35.45

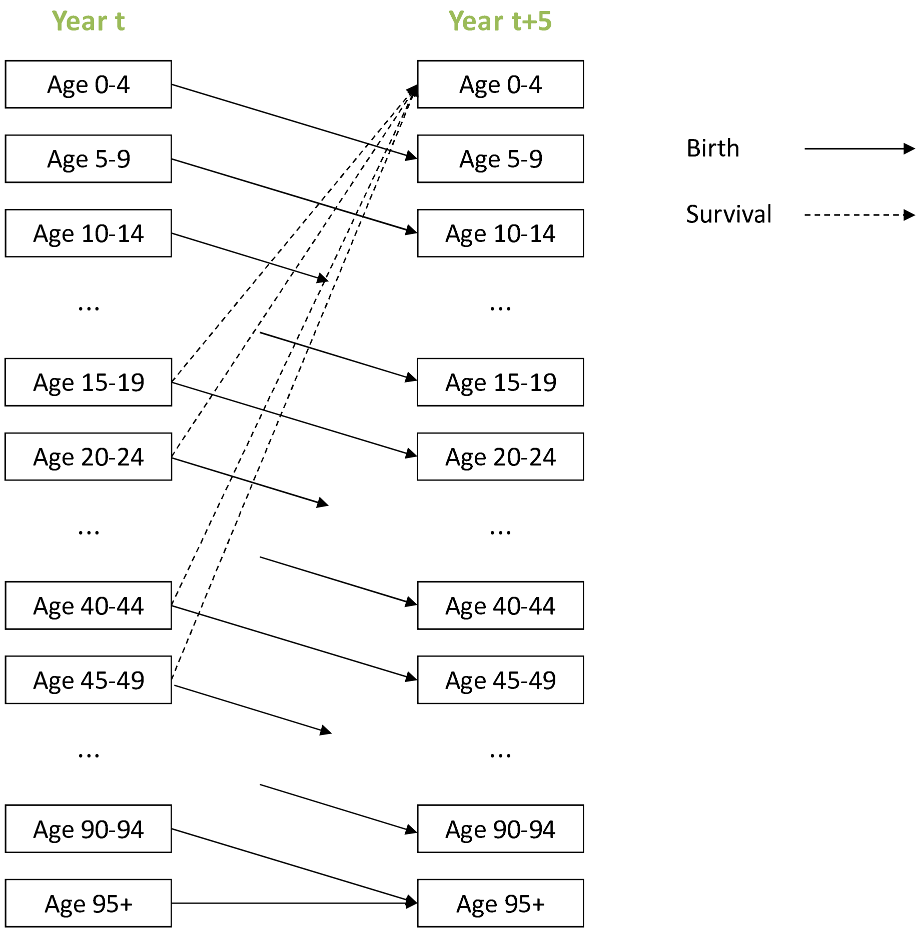


Figure 4.2 The cohort-component method of population projection

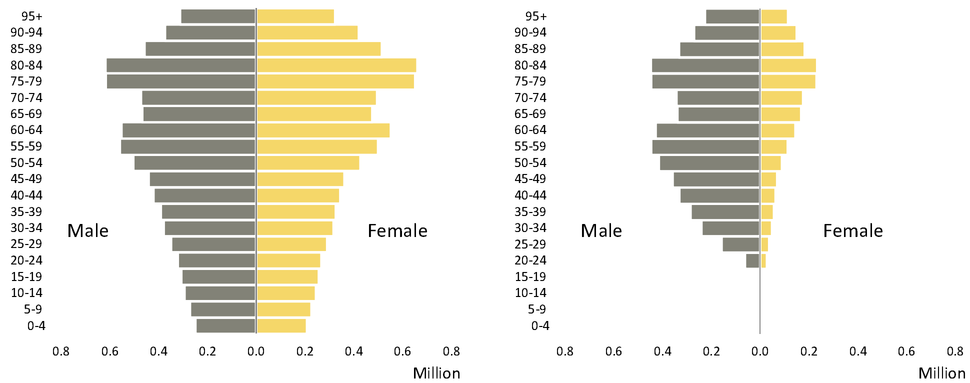


Figure 4.3 Projected population pyramid (left) and household pyramid (right) of Beijing in 2050

4.1.2 Verification of Projected Results

Such a population projection at district level is not exiting in the current reference literatures. To verify the reliability of the original population projection in this study, the projected results have been summed up to confirm with national level projection that conducted by other reference research.

Figure 4.4 shows the comparison of 2020's population projection (Chen, 2009). Figure 4.5 shows the comparison of 2050's. The 2020's estimates are rather close to reference's projection. While 2050's estimates show some mismatch with the reference's projection, probably due to the handling of mortality rate and migration rate. In this study, mortality rate is a group of static data from one certainty year, and migration rate has not been taken into account. In the future, when it is possible to obtain sufficient data for population projection, it's necessary to re-conduct this projection at a higher accurate level.

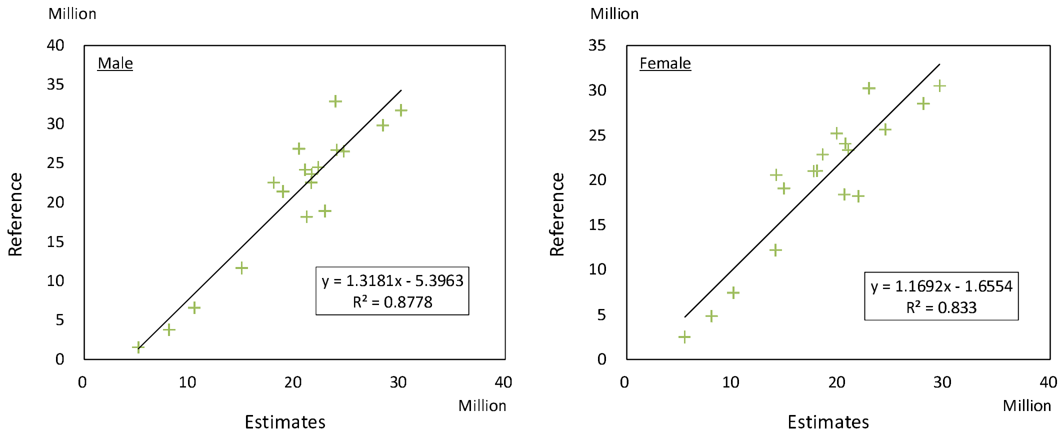


Figure 4.4 Comparison of the 2020's population projection

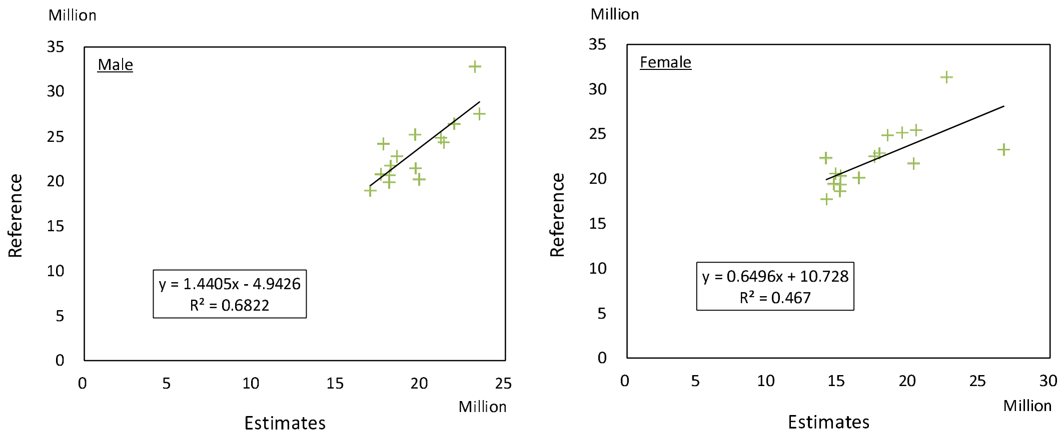
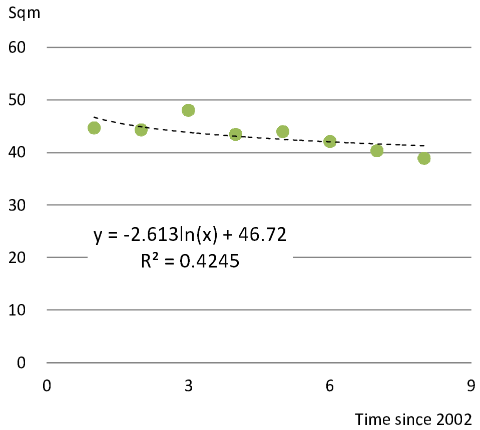


Figure 4.5 Comparison of 2050's population projection

4.2 Floor Area Database

It would be preferable to project floor areas base on cohort-component method. However, the essential information of creating cohort, such like constructing rate of new buildings or demolition rate by building age is impossible to be gathered at this moment. Therefore, in this study floor area is projected simply by trend analysis.

First the regression analysis has been applied on the statistics of floor area per household between 2002 and 2009 (Figure 4.6). Then based on the regression equation floor area per household was projected through 2050, which was then times with total household numbers (see 4.1) to get the total floor area. The statistical data all refers to Chinese year books. While Beijing's data seems numerical reliable, in some regions statistical data lacks continuity and is rather hard to apply trend analysis. In such cases a part of the past statistics is collected to set up regression equation. The regional projections of floor area are listed in appendix 3.



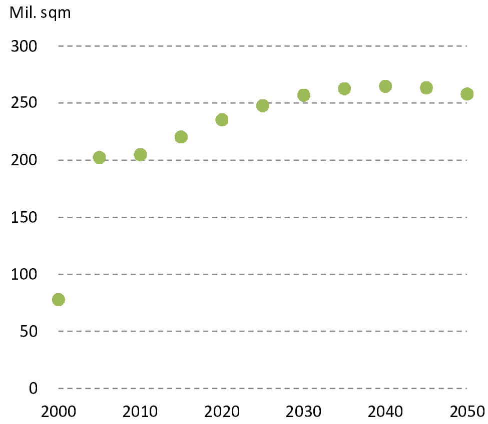


Figure 4.6 Regression analysis of floor area per household (left) and projected total floor area (right) of Beijing's urban residential building

4.3 Appliances Database

4.3.1 Ownership of Household Appliance

In this study 8 kinds of home appliances: washing machine, refrigerator, Television, computer, stereo system, micro-wave, vacuum cleaner, and gas stove are included in appliance endues. Same as floor area's projection, using trend analysis the numbers of appliances per household are projected through 2050 as well. However, the number of gas stove is set as one unit per household with no variation in the future.

Figure 4.7 shows the statistic data (China Yearbook) of 7 home appliances' number owned per 100 households with correspondence regression formulas. Using regression formulas the ownership numbers could be predicted through 2050. Figure 4.8 illustrates the projection of home appliances of Beijing. The regional projections are listed in Appendix 4.

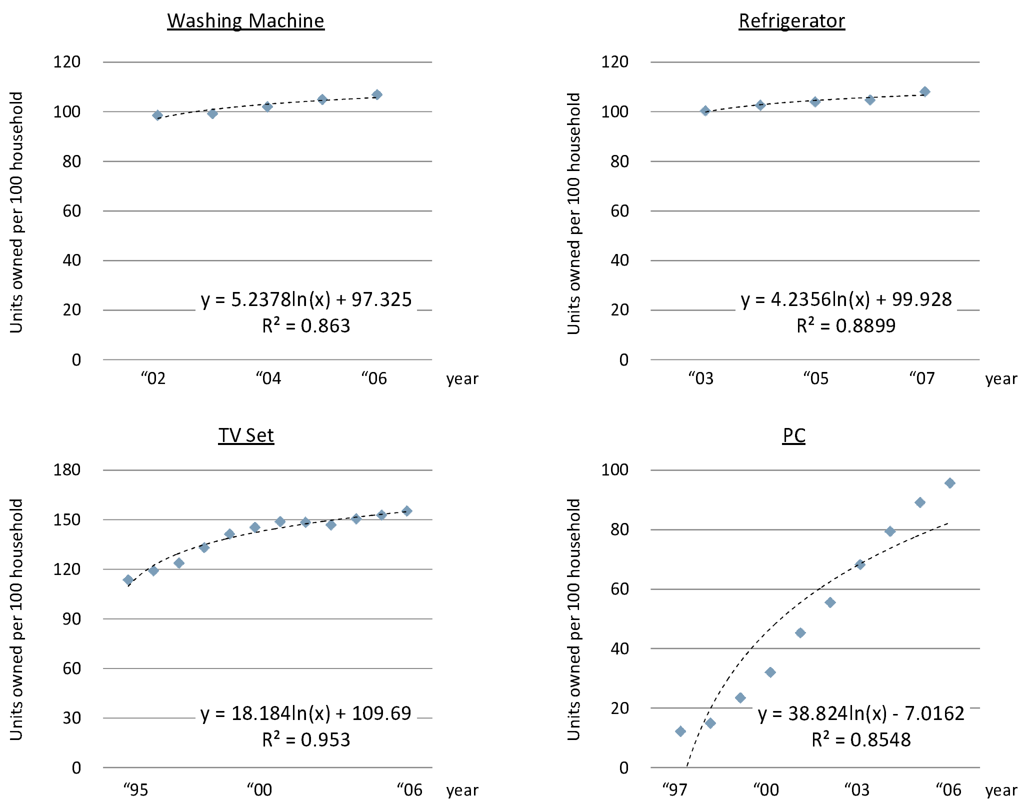


Figure 4.7.1 Regression analysis of appliances' numbers owned per 100 household (part 1)

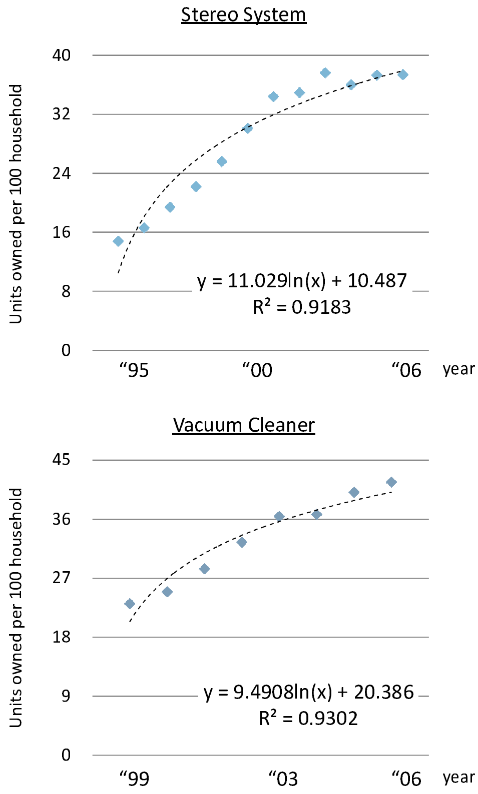


Figure 4.7.2 Regression analysis of appliances' numbers owned per 100 household (part 2)

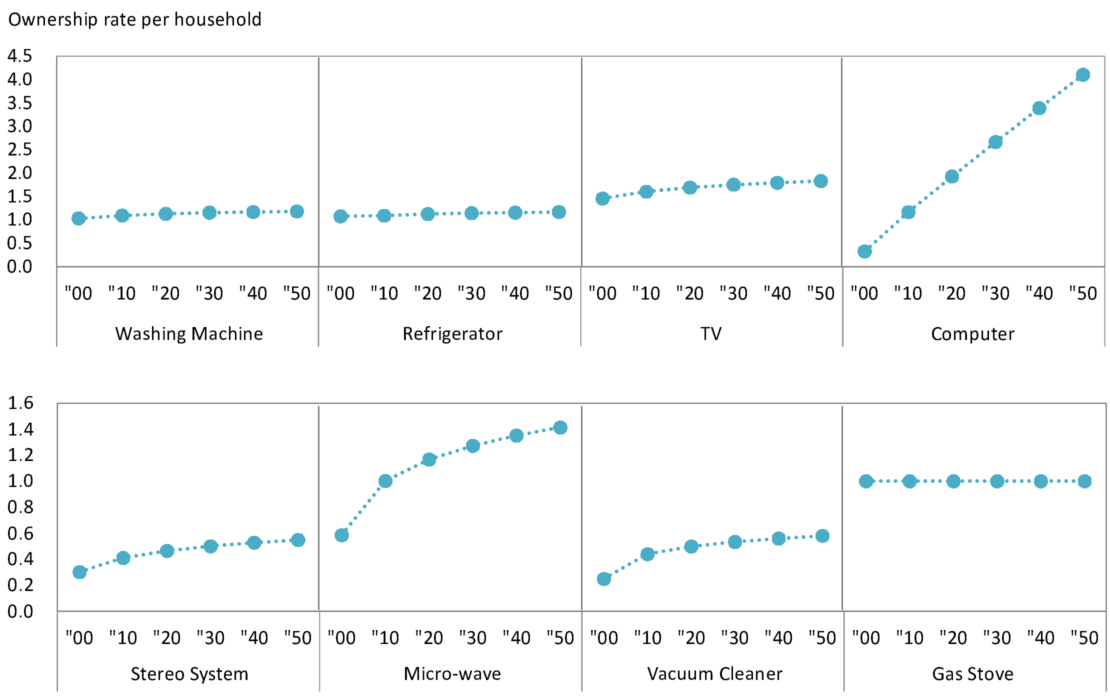


Figure 4.8 Projected ownership rates of home appliances (Beijing)

4.3.2 Operation Condition of Household Appliance

Table 4.2 summarizes the operation condition of 8 household appliances. Most of those settings refer to the SCHEDULE program developed by SHASE (The Society of Heating, Air-conditioning and Sanitary Engineers of JAPAN). The working power of stove is related to the average household size. Operation times were later adjusted during model calibration (see chapter 5).

Table 4.2 Operation condition of household appliances

	Working Power (W)	Standby Power (W)	Operation Time (h/day)
Washing Machine	86.00	0.00	1.00
Refrigerator	20.80	0.00	24.00
TV Set (color)	60.50	0.40	8.00
Computer	100.00	10.00	8.00
Stereo System	74.00	0.50	1.00
Micro-wave	1200.00	1.20	0.34
Stove	234.6×HH+253.2	0.00	6.00
Vacuum Cleaner	1332.00	0.00	0.25

4.4 Heating and Cooling Database

Input parameters of heating and cooling load include heat transmission coefficient, operation hours and air conditioners' temperature. Table 4.3 gives these parameters settings of different climate areas.

Although Chinese residential buildings ought to be designed following some certain building codes, in the real case not all the buildings fulfill such a standard. There is no verified national wild data of heat transmission coefficient as well. Because of the above grounds, after model calibration (see chapter 5), the heat transmission coefficient of each area has been adjusted around 140% of Japanese old standard (Ikaga, 2005).

The settings of air conditioners' temperature and operation hours refer to several field survey researches (Cai, 2007; Yu, 2008; Liu, 2007).

Table 4.3 Parameter settings of heating and cooling

		Severe cold	Cold	HSCW	Temperate	HSWW
Heat Transmission Coefficient (W/m^2K)	FT	4.47	4.47	4.47	4.47	4.47
	RS	2.38	2.62	2.89	3.95	3.95
Room Temperature (°C)	Heating	18	23	23	23	23
	Heating AS	16	21	21	21	21
	Cooling	26	26	25	25	25
	Cooling AS	28	28	27	27	27
Operation Hours (h)	Heating	24	24	8	8	8
	Heating AS	18	18	6	6	6
	Cooling	-	8	8	8	16
	Cooling AS	-	6	6	6	12

HSCW: Hot Summer Cold Winter HSWW: Hot Summer Warm Winter

4.5 Solar Energy

China is divided into 5 radiation zones based on the anural amount of solar radiation. In this study each district's anural amount of solar radiation refers to its capital city's value (Zhang, 2003) which is listed in Table 4.4.

Table 4.4 Anural amount of solar radiation

Region	Reference City	Area	Radiation Intensity		Similar Radiation Area
			$MJ/m^2 \cdot year$	$kWh/m^2 \cdot year$	
Qinghai	Xining	1	5634	1565	Northern India
Tibet	Lhasa	1	7655	2127	
Xinjiang	Urumqi	1	5174	1437	
Ningxia	Yinchuan	1	5961	1656	
Gansu	Lanzhou	1	5096	1416	
Inner Mongolia	Hohhot	2	4880	1356	Jakarta, Indonesia
Beijing	Beijing	2	5013	1393	
Tianjin	Tianjin	2	4836	1343	
Hebei	Shijiazhuang	2	5013	1393	
Shanxi	Taiyuan	2	5067	1408	
Jilin	Changchun	3	5066	1407	Washington D.C., the U.S.
Liaoning	Shengyang	3	4880	1356	
Shandong	Jinan	3	4871	1353	
Shaanxi	Xi'an	3	4509	1253	
Anhui	Hefei	3	4675	1299	
Henan	Zhenzhou	3	4879	1355	
Jiangsu	Nanjing	3	4524	1257	
Yunnan	Kunming	3	5684	1579	
Guangdong	Guangzhou	3	4092	1137	
Fujian	Fuzhou	3	4490	1247	
Hainan	Haikou	3	4092	1137	
Heilongjiang	Harbin	4	4997	1388	Milan, Italy
Shanghai	Shanghai	4	4682	1301	
Hunan	Changsha	4	4132	1148	
Zhejiang	Hangzhou	4	4524	1257	
Hubei	Wuhan	4	4497	1249	

Region	Reference City	Area	Radiation Intensity		Similar Radiation Area
			$MJ/m^2 \cdot year$	$MJ/m^2 \cdot year$	
Jiangxi	Nanchang	4	4610	1281	
Guangxi	Nanning	4	4455	1238	
Sichuan	Chengdu	5	3307	919	Most EU countries
Guizhou	Guiyang	5	3766	1046	
Chongqing	Chongqing	5	3410	947	

(1 MJ/m^2 =0.2778 kWh/m^2)

4.6 Energy Source Share and CO_2 Intensity

The coal-fired boilers are wildly used in northern China as residential heating equipment. On the other hand, air conditioners are the main equipment for both heating and cooling in southern China. Therefore the energy source of heating in the northern districts is set as coal while the energy source of cooling and heating in the southern districts is set as electricity.

As for DHW and cooking equipment, first energy ratio of city gas is set based on “population of gas users” from Chinese year book. There are 3 kinds of gas which are currently used as city gas: LPG, nature gas, and coal gas. Unfortunately the regional energy ratio of DHW appliance is unclear. A case study (Cai, 2007) reviews that electric water heater holds about 10% in Shanghai’s families. After calibrating with recorded electricity consumption (Chinese year book), in most districts the final ratio of electricity and gas is set as 20% and 80%, respectively.

The energy source ratio of DHW appliance is illustrated in Figure 4.9.

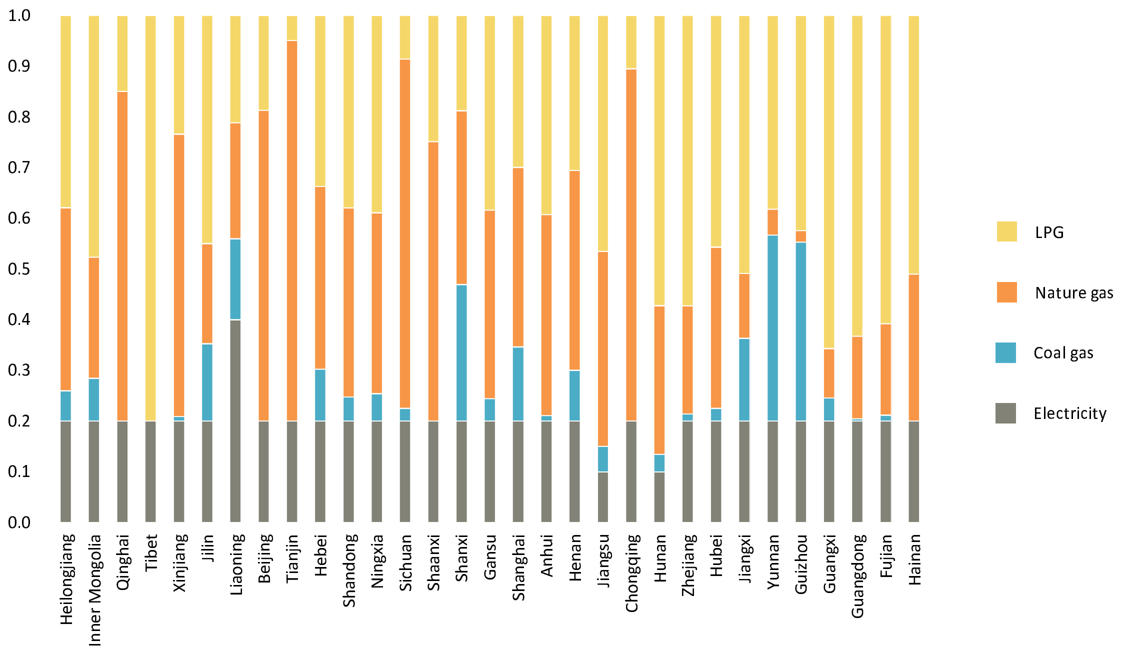


Figure 4.9 Regional energy source ratio of DHW appliance

Although most of the electricity generation depends on thermal power, after the Three Gorges Dam fully functioned in May 2010, electricity generation from hydropower reaches 20% (Figure 4.10 left) of the total electric generating capacity in China. Figure 4.10 (right) shows the hydropower’s ration of each province.

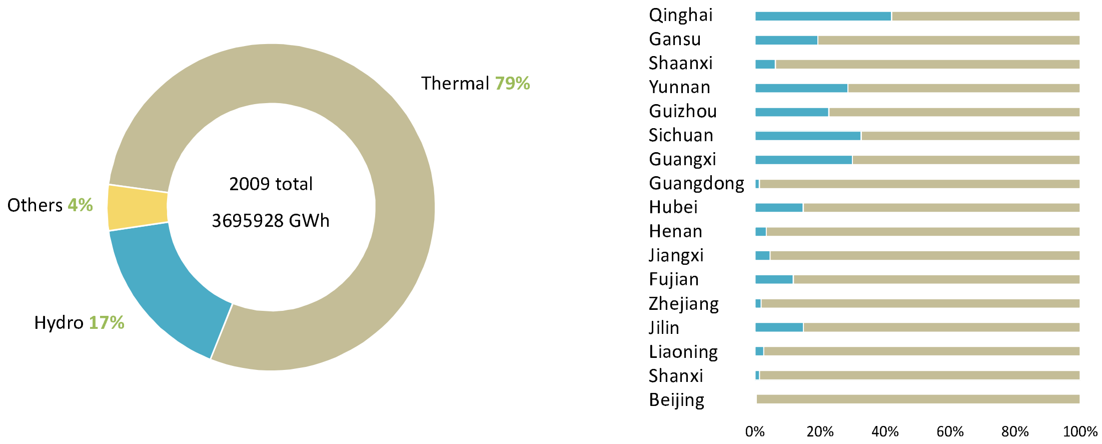


Figure 4.10 Energy source ratio of electricity generating capacity (left) and regional hydropower (right)

4.7 Investment Cost and Energy Bill

Research related to the AIM endues model (NIES, 2009) includes many investment cost and payback time of efficiency technologies. Due to the reason that most results conducted by AIM are based on Japanese cost standard, here all the costs have been convert into Chinese cost value with respect of relative exchange rate (BLS, 2011). The costs of eco-appliances (refrigerator and television) refer to the price gap between non-eco models and eco models in the regular Chinese electronic market. Investment cost of photovoltaic solar energy generation in china is about 9600 USD per kW (Ma, 2010), and maintenance fee per year is set as 10% of the initial cost. The converted costs and payback times that listed in Table 4.5 are used to calculate marginal abatement cost of low carbon technologies. While for behavioral change related efficiency policies, energy bills for electricity, city gas and central heating are used to calculate the financial profits that brought by energy saving actions. Energy bills of all districts are listed in Table 4.6. Despise that the energy bills in the same district slightly differ from city to city, for each district we take one major city (usually the district's capital city) as the reference subject.

Table 4.5 Investment cost and payback time

	Initial Investment Cost	Payback Time (year)
Thermal retrofit	1166.29 USD per household	15
Eco-appliances	Refrigerator 160 USD, TV 195 USD (per unit)	8
High efficiency lighting	15.35 USD per household	8
Solar water heater	153 USD per household	10
Photovoltaic generation	Installation 9600 USD per kW, maintenance 960 USD per year (10% of installation cost)	20

Table 4.6 Energy bills of 31 Chinese districts

Region	Reference City	Electricity USD/kWh	City Gas USD/m^3	Heating USD/Year/m^2
Heilongjiang	Harbin	0.08	0.32	6.46
Inner Mongolia	Hohhot	0.06	0.23	3.53
Qinghai	Xining	0.07	0.17	3.52
Tibet	Lhasa	0.06	0.21	3.52
Xinjiang	Urumqi	0.07	0.21	3.52
Jilin	Changchun	0.08	0.32	4.64
Liaoning	Shengyang	0.07	0.38	4.48
Beijing	Beijing	0.07	0.30	4.80
Tianjin	Tianjin	0.07	0.32	4.00
Hebei	Shijiazhuang	0.08	0.35	4.00
Shandong	Jinan	0.08	0.32	4.32
Ningxia	Yinchuan	0.07	0.20	3.12
Sichuan	Chengdu	0.07	0.23	-
Shaanxi	Xi'an	0.08	0.26	4.64
Shanxi	Taiyuan	0.08	0.34	3.84
Gansu	Lanzhou	0.08	0.23	3.36
Shanghai	Shanghai	0.10	0.34	-
Anhui	Hefei	0.09	0.34	-
Henan	Zhenzhou	0.08	0.26	-
Jiangsu	Nanjing	0.08	0.35	-
Chongqing	Chongqing	0.07	0.18	-
Hunan	Changsha	0.09	0.36	-
Zhejiang	Hangzhou	0.08	0.38	-
Hubei	Wuhan	0.08	0.37	-
Jiangxi	Nanchang	0.09	0.51	-
Yunnan	Kunming	0.06	0.18	-
Guizhou	Guiyang	0.06	0.17	-
Guangxi	Nanning	0.07	0.70	-
Guangdong	Guangzhou	0.10	0.55	-
Fujian	Fuzhou	0.07	0.58	-
Hainan	Haikou	0.10	0.34	-

4.8 Summary

This chapter specifically focused on database constructing. In order to conduct an emission evaluation through 2050, the parameter inputs such like household number and ownership of appliances have to be projected follow the time series. The cohort component method has been applied to project household number and size. While for floor area and ownership of household appliances, the projection were based on regression analysis of the past statistics. The operation condition of each appliance was set according to reference literatures. Later a few of the parameter settings have been modified to match the macro statistics of energy consumption.

The database of energy source share was based on statistics of energy source penetration rates from Chinese yearbook. Other appliance usage related parameter inputs were first set based on certain literatures, and later adjusted to match the macro statistics of energy consumption (see chapter 5).

Chapter 5

Model Calibration

"Trust, but verify". (Russian proverb)

CONTENTS

The initial estimates from CO_2 emission sub-model have showed some mismatches with historical statistical data of year 2000 and 2005. Therefore database and modeling process have been calibrated in order to ensure the evaluation model is well able to reproduce the historic trends. This chapter mainly introduces model calibration and corrected estimating results.

5.1 Modification of the Database

There are certain parameter inputs in the evaluation model that are based on assumptions, such like shower frequency, appliance usage pattern. In most cases the specific information from a few case studies (ref) has been applied to all the regions. This however leads to a mismatch with the macro statistics.

Another reason that caused the mismatch is the difference between energy demand and actual consumption. During the estimating process of energy consumption, the evaluation model simply calculates the total demand of residential sector despise that in some areas the demand has not been fully satisfied due the limited financial resource. Therefore it is necessary to bring in penetration coefficient of end-uses and convert energy demand to actual energy consumption.

The model calibration includes the following 2 steps:

1. The assumed inputs have been modified in order to match estimates outputs with macro statistical data.
2. Penetration coefficient of each end-use has been introduced into the evaluation model. Table 5.1 – 5.4 show the specific settings of each end-use by district. The basic penetration coefficients of year 2000 and 2005 are determined after calibration adjustment with statistic data.

Table 5.1 Penetration coefficients of heating use (%)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Heilongjiang	20	20	30	35	40	50	60	70	80	90	100
Inner Mongolia	20	20	30	35	40	50	60	70	80	90	100
Qinghai	20	20	30	35	40	50	60	70	80	90	100
Tibet	20	20	30	35	40	50	60	70	80	90	100
Xinjiang	20	20	30	35	40	50	60	70	80	90	100
Jilin	20	20	30	35	40	50	60	70	80	90	100
Liaoning	20	20	30	35	40	50	60	70	80	90	100
Beijing	20	20	30	35	40	50	60	70	80	90	100
Tianjin	20	20	30	35	40	50	60	70	80	90	100
Hebei	20	20	30	35	40	50	60	70	80	90	100
Shandong	20	20	30	35	40	50	60	70	80	90	100
Ningxia	20	20	30	35	40	50	60	70	80	90	100
Sichuan	5	10	20	30	40	50	60	70	80	90	100
Shaanxi	20	20	30	35	40	50	60	70	80	90	100
Shanxi	20	20	30	35	40	50	60	70	80	90	100

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Gansu	20	20	30	35	40	50	60	70	80	90	100
Shanghai	5	10	20	30	40	50	60	70	80	90	100
Anhui	5	5	15	30	40	50	60	70	80	90	100
Henan	10	5	15	30	40	50	60	70	80	90	100
Jiangsu	20	10	20	30	40	50	60	70	80	90	100
Chongqing	15	5	15	30	40	50	60	70	80	90	100
Hunan	5	5	15	30	40	50	60	70	80	90	100
Zhejiang	5	5	15	30	40	50	60	70	80	90	100
Hubei	5	5	15	30	40	50	60	70	80	90	100
Jiangxi	5	5	15	30	40	50	60	70	80	90	100
Yunnan	5	10	20	30	40	50	60	70	80	90	100
Guizhou	5	10	20	30	40	50	60	70	80	90	100
Guangxi	20	10	20	30	40	50	60	70	80	90	100
Guangdong	20	10	20	30	40	50	60	70	80	90	100
Fujian	5	10	20	30	40	50	60	70	80	90	100
Hainan	5	10	20	30	40	50	60	70	80	90	100

Table 5.2 Penetration coefficients of cooling use (%)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Jilin	20	30	40	50	60	70	80	90	100	100	100
Liaoning	20	30	40	50	60	70	80	90	100	100	100
Beijing	20	30	40	50	60	70	80	90	100	100	100
Tianjin	20	30	40	50	60	70	80	90	100	100	100
Hebei	20	30	40	50	60	70	80	90	100	100	100
Shandong	20	20	30	40	50	60	70	80	90	100	100
Ningxia	20	30	40	50	60	70	80	90	100	100	100
Sichuan	20	30	40	50	60	70	80	90	100	100	100
Shaanxi	20	30	40	50	60	70	80	90	100	100	100
Shanxi	20	30	40	50	60	70	80	90	100	100	100
Gansu	20	30	40	50	60	70	80	90	100	100	100
Shanghai	20	30	40	50	60	70	80	90	100	100	100
Anhui	20	20	30	40	50	60	70	80	90	100	100
Henan	25	25	40	50	60	70	80	90	100	100	100
Jiangsu	30	10	20	30	40	50	60	70	80	90	100
Chongqing	40	20	30	40	50	60	70	80	90	100	100

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Hunan	10	10	20	30	40	50	60	70	80	90	100
Zhejiang	10	10	20	30	40	50	60	70	80	90	100
Hubei	20	25	40	50	60	70	80	90	100	100	100
Jiangxi	25	10	20	30	40	50	60	70	80	90	100
Yunnan	20	30	40	50	60	70	80	90	100	100	100
Guizhou	20	30	40	50	60	70	80	90	100	100	100
Guangxi	40	20	30	40	50	60	70	80	90	100	100
Guangdong	40	20	30	40	50	60	70	80	90	100	100
Fujian	40	20	30	40	50	60	70	80	90	100	100
Hainan	10	15	20	30	40	50	60	70	80	90	100

Table 5.3 Penetration coefficients of hot water use (%)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Heilongjiang	80	80	90	100	100	100	100	100	100	100	100
Inner Mongolia	20	40	50	60	70	80	90	100	100	100	100
Qinghai	70	70	80	90	100	100	100	100	100	100	100
Tibet	20	30	40	50	60	70	80	90	100	100	100
Xinjiang	60	60	70	80	90	100	100	100	100	100	100
Jilin	40	40	50	60	70	80	90	100	100	100	100
Liaoning	20	40	50	60	70	80	90	100	100	100	100
Beijing	50	55	60	70	80	90	100	100	100	100	100
Tianjin	40	45	50	60	70	80	90	100	100	100	100
Hebei	60	60	70	80	90	100	100	100	100	100	100
Shandong	15	15	20	30	40	50	60	70	80	90	100
Ningxia	30	40	50	60	70	80	90	100	100	100	100
Sichuan	50	40	40	50	60	70	80	90	100	100	100
Shaanxi	40	30	40	50	60	70	80	90	100	100	100
Shanxi	25	25	40	50	60	70	80	90	100	100	100
Gansu	45	45	50	60	70	80	90	100	100	100	100
Shanghai	30	35	40	50	60	70	80	90	100	100	100
Anhui	40	20	30	40	50	60	70	80	90	100	100
Henan	30	10	20	30	40	50	60	70	80	90	100
Jiangsu	20	10	20	30	40	50	60	70	80	90	100
Chongqing	40	20	30	40	50	60	70	80	90	100	100
Hunan	25	25	40	50	60	70	80	90	100	100	100

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Zhejiang	20	20	30	40	50	60	70	80	90	100	100
Hubei	20	25	40	50	60	70	80	90	100	100	100
Jiangxi	25	25	40	50	60	70	80	90	100	100	100
Yunnan	50	55	60	70	80	90	100	100	100	100	100
Guizhou	65	70	80	90	100	100	100	100	100	100	100
Guangxi	40	10	20	30	40	50	60	70	80	90	100
Guangdong	30	30	40	50	60	70	80	90	100	100	100
Fujian	40	20	30	40	50	60	70	80	90	100	100
Hainan	25	30	40	50	60	70	80	90	100	100	100

Table 5.4 Penetration coefficients of household appliances use (%)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Heilongjiang	50	50	60	70	80	90	100	100	100	100	100
Inner Mongolia	10	50	60	70	80	90	100	100	100	100	100
Qinghai	90	90	100	100	100	100	100	100	100	100	100
Tibet	50	60	70	80	90	100	100	100	100	100	100
Xinjiang	60	60	70	80	90	100	100	100	100	100	100
Jilin	60	60	70	80	90	100	100	100	100	100	100
Liaoning	50	70	80	90	100	100	100	100	100	100	100
Beijing	80	85	90	100	100	100	100	100	100	100	100
Tianjin	60	65	70	80	90	100	100	100	100	100	100
Hebei	50	55	60	70	80	90	100	100	100	100	100
Shandong	60	45	60	70	80	90	100	100	100	100	100
Ningxia	60	70	80	90	100	100	100	100	100	100	100
Sichuan	90	60	70	80	90	100	100	100	100	100	100
Shaanxi	70	70	80	90	100	100	100	100	100	100	100
Shanxi	55	50	60	70	80	90	100	100	100	100	100
Gansu	100	70	80	90	100	100	100	100	100	100	100
Shanghai	55	60	70	80	90	100	100	100	100	100	100
Anhui	60	40	50	60	70	80	90	100	100	100	100
Henan	60	30	40	50	60	70	80	90	100	100	100
Jiangsu	50	30	40	50	60	70	80	90	100	100	100
Chongqing	70	50	60	70	80	90	100	100	100	100	100
Hunan	40	45	50	60	70	80	90	100	100	100	100
Zhejiang	50	40	50	60	70	80	90	100	100	100	100

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Hubei	50	50	60	70	80	90	100	100	100	100	100
Jiangxi	50	40	50	60	70	80	90	100	100	100	100
Yunnan	80	85	90	100	100	100	100	100	100	100	100
Guizhou	80	85	90	100	100	100	100	100	100	100	100
Guangxi	60	30	40	50	60	70	80	90	100	100	100
Guangdong	70	50	60	70	80	90	100	100	100	100	100
Fujian	70	60	70	80	90	100	100	100	100	100	100
Hainan	25	25	30	40	50	60	70	80	90	100	100

5.2 Calibration of Model's Outputs

5.2.1 Calibration with Macro Statistics

Figure 5.1 shows the comparison of anural electricity consumptions between model estimates and macro statistics in year 2000 and 2005. In each graph, vertical axis represents statistical data and horizontal axis represents model estimates. The graph also gives regression equation that reviews the relationship between model estimates and macro statistics. The fact that the slope of each equation is very close to 1 proves that the estimates from evaluation model generally well matches with historic data. Most of those dots that have large divergence between horizontal and vertical value represent districts from the northwest of China, like Qinghai or Ningxia, where the reliability of statistics data needs to be further confirmed.

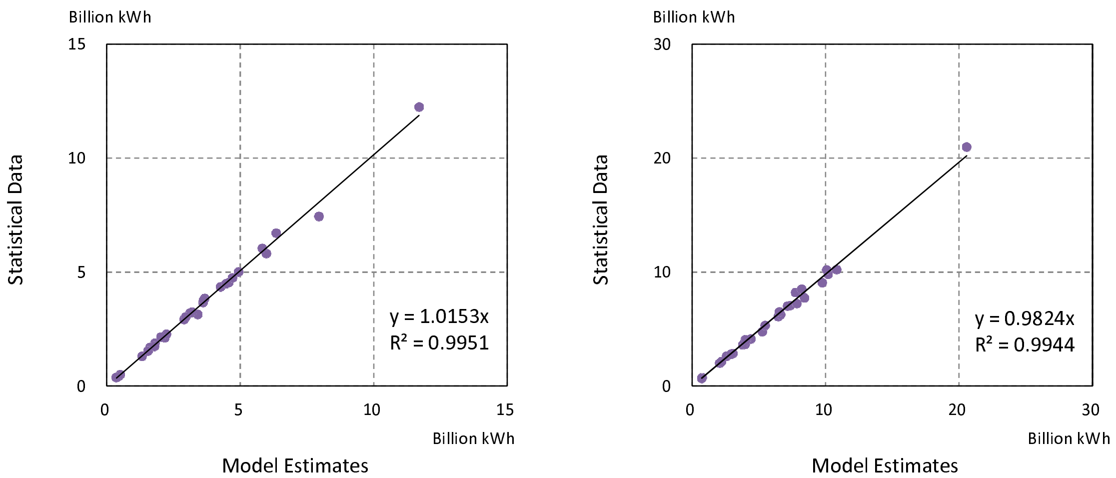


Figure 5.1 Comparison of model estimates and macro statistics in 2000 (left) and 2005 (right)

5.2.2 Calibration with Field Measurement

During year 2006 and 2008, a research group from Tohoku University conducted a large-scale field measurement research on Chinese residential energy consumption (H.Yoshino, 2009). The general information about the subjected household is listed in appendix 12. The research involved 6 Chinese cities, and measured anural energy consumption from end-use including heating, cooling, domestic hot water, lighting and other appliance in 12 households (2 households per city). In this section the model estimates of 2005 have been compared with measured value to see if the model could well represent the real consumption situation.

Figure 5.2 shows the regression results of model estimates and measurement data. Some of the dots appear to be away from the diagonal line, but overall the model estimates match with the measurement data.

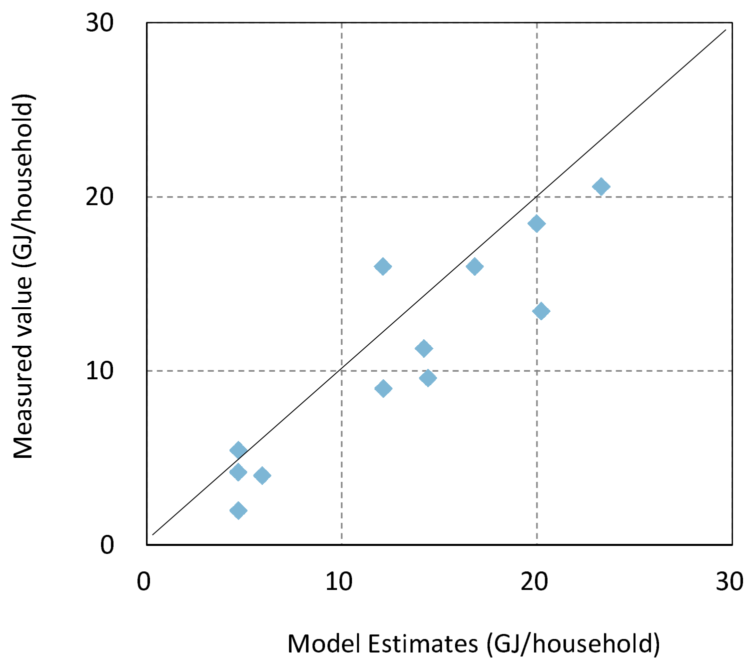


Figure 5.2 Comparison of model estimates and measurement data

5.3 Summary

In this chapter the evaluation model has been thoroughly examined of whether it could accurately review the reality of energy consumption system. Although several input parameters were set based on assumptions, after necessary adjustment, estimates from evaluation model generally well matches with historic data.

Obviously there are many directions for the model to improve its accuracy. Based on the present modeling experiences the following modifications and extensions are listed as high-priority ones:

1. The accurate insulation level of the exiting residential buildings, preferably gathered by field research.
2. The living standard (or usage status of heating, cooling, DHW etc.) of households at different income levels.

Chapter 6

Estimated Results and Uncertainty Analysis

"The flap of a butterfly's wings in Brazil set off a tornado in Hiyoshi". (Butterfly effect)

CONTENTS

The reliability of the evaluation model has been proved by data calibration. Now it is possible to conduct a future prediction for both CO_2 emission and marginal abatement cost. This chapter first gives estimated results of CO_2 reduction potentials and marginal abatement cost. Then the estimated results are applied with uncertainty analysis conducted by Monte Carlo simulation. This chapter also give an in-depth assessment of efficiency polices.

6.1 Projected CO_2 Emissions

Figure 6.1 – 6.3 illustrates the projected CO_2 emissions by end use in 3 climatic representative districts. In frozen technology scenario, CO_2 emissions in the 3 districts see an aggressive increase over year 2050 compare with the 2000 level. With government plotted efficiency policies in the reference scenario, the emission will drop about 30% compare with frozen technology estimates. While the maximum reduction rate reaches 70% in the abatement scenario.

Figure 6.4 shows the same projections by energy source. In Beijing where the biggest energy consumer regional heating relies on coal as fuel source, coal accounts for over 50% of the total energy consumption. While in Shanghai and Guangdong where most of the household power relies on electricity, electricity accounts for almost 90% of the total energy consumption. And the electricity caused CO_2 emission could be reduces by power generation efficiency and renewable energy utilization.

Figure 6.5 shows the overall results of all 31 districts in year 2050. In the northern cold area, central heating will still be the major energy consumer in the future, which means reference scenario will have larger contributions for emission reduction. This balance sees a turnover in the southern area where energy resource mainly relies on electricity, which gives a clear point of view that in such area efficient electricity generation is reasonably needed as well as the technology innovation of household appliances. Reduction rate of reference scenario gets smaller from north to south. The top 3 FT compared emission drops occur in Tibet (51.33%), Inner Mongolia (48.21%) and Xinjiang (47.98%). On the other hand, reduction rate of abatement scenario gets bigger from north to south. The top 3 FT compared emission drops occur in Shanghai (71.01%), Jiangsu (70.17%) and Zhejiang (70.15%).

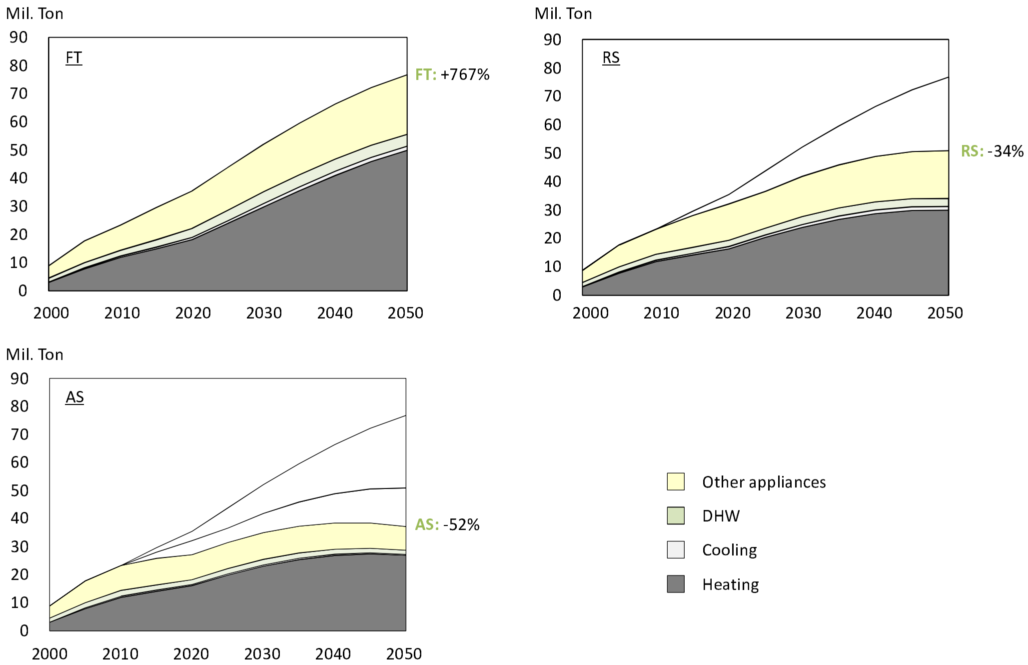


Figure 6.1 Projected CO_2 emissions by scenario (Beijing)

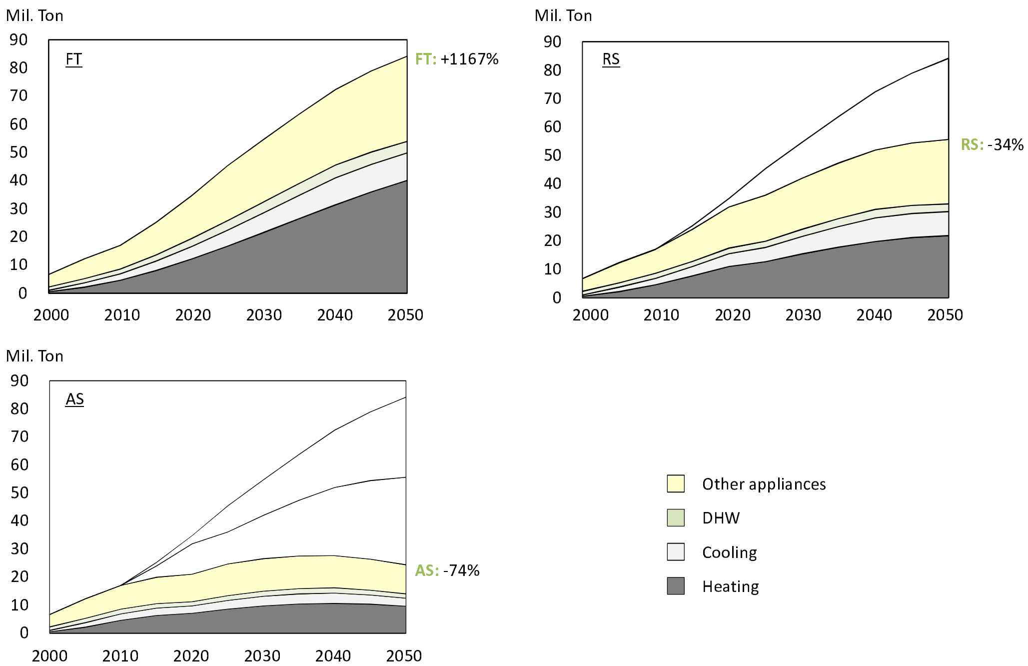


Figure 6.2 Projected CO_2 emissions by scenario (Shanghai)

FT: Frozen Technology RS: Reference Scenario AS: Abatement Scenario

FT increase rates are compared to 2000 emission level

RS, AS reduction rates are compared to frozen technology level

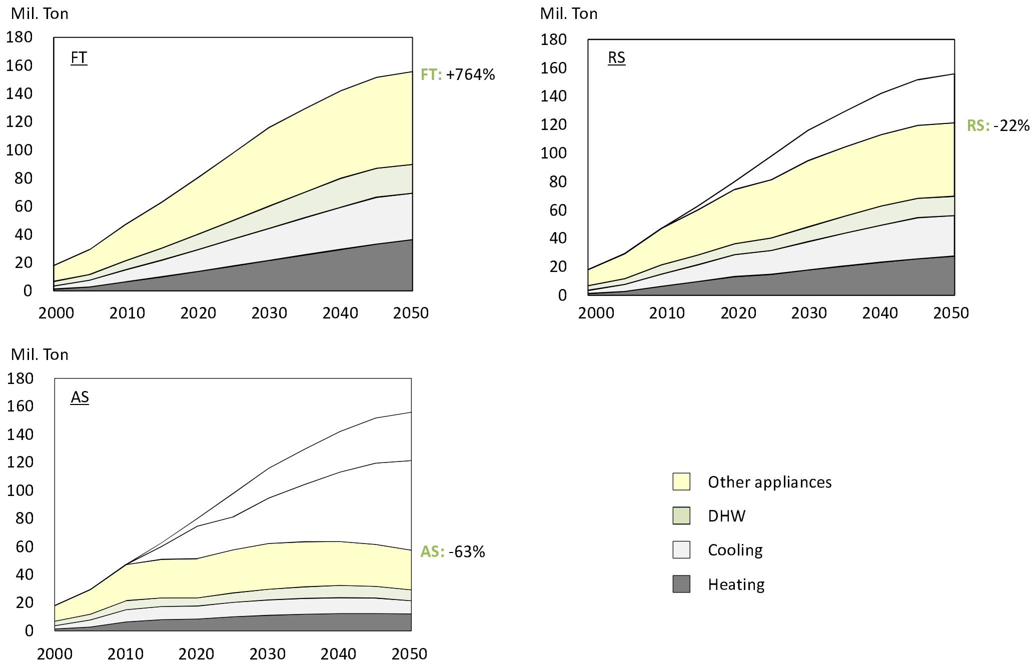


Figure 6.3 Projected CO_2 emissions by scenario (Guangdong)

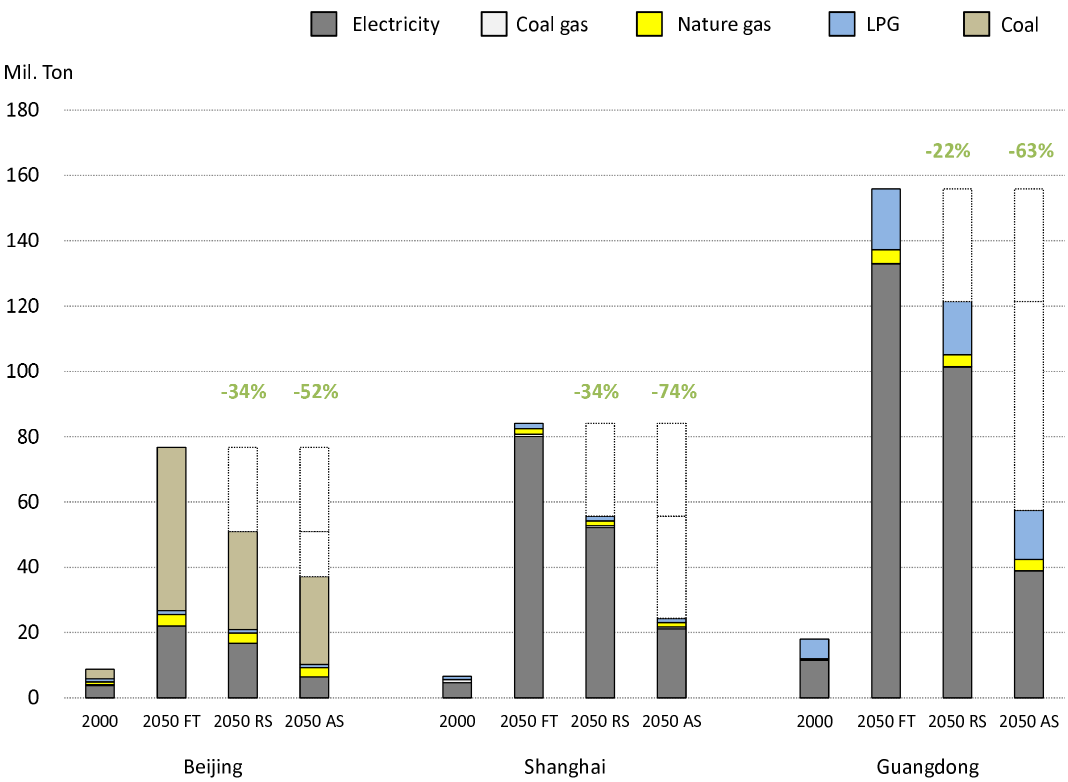


Figure 6.4 Projected CO_2 emissions by energy source

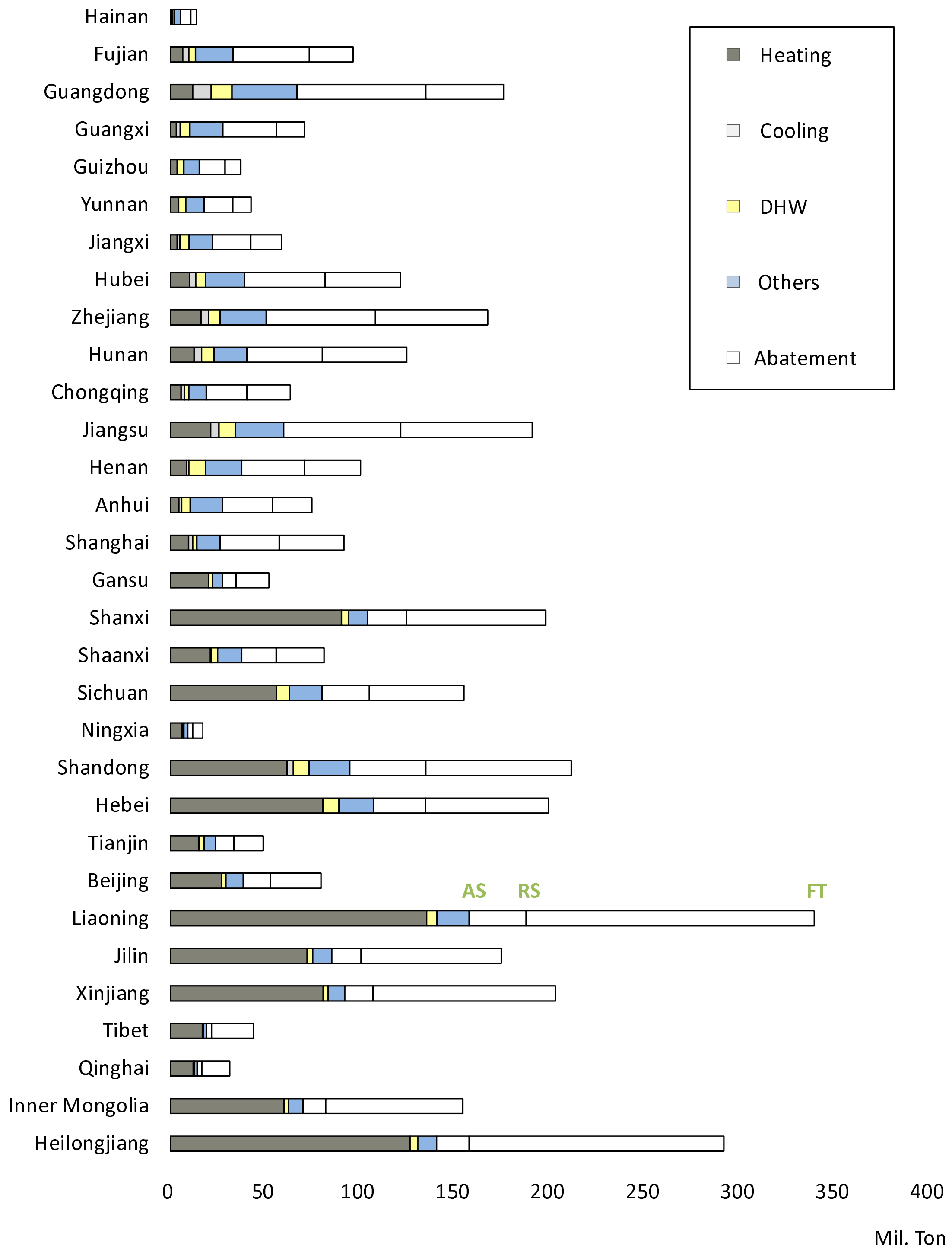


Figure 6.5 Projected CO_2 emissions and reduction potential in year 2050 (all districts)

FT: Frozen Technology RS: Reference Scenario AS: Abatement Scenario

DHW: Domestic Hot Water

6.2 Lifestyle vs. Technology

The executors of efficiency policies could be divided into 4 major groups: residents, technology developers, electricity industry, and renewable energy industry. Thus emission abatement potential is also examined from a point view of policy executors.

Figure 6.6 shows the breakdowns of emission reduction from each policy executor. Included in the figure those are outputs of 3 climatic representative districts. In a cold area such like Beijing, equipment improvement that includes thermal retrofit appears to be contributing the major part (24.8 megatons in year 2050) of CO_2 reduction. On the other hand, efforts from electricity area are efficient in the area with a milder climate. Take Shanghai as an example, improvement of electricity intensity alone could bring 27.4 megatons of CO_2 abatement, which is almost half of the whole abatement amount. Another interesting finding occurs in the south area. In Guangdong's breakdown, abatement contribution of equipment improvement appears to be extremely small, while efforts from electricity industry contributed more than half of the total reductions.

Comparing to other 3 executors renewable energy industry has minor contributions of CO_2 reduction in all 3 districts. None of the 3 districts has a rich resource of solar radiation, and the penetration rate of solar energy utilization was set considerably low in the efficiency scenarios.

Nevertheless, behavioral changes contribute a respectively significant amount of CO_2 reduction in all 3 districts. The implementation of low carbon lifestyle will play an important role in the future.

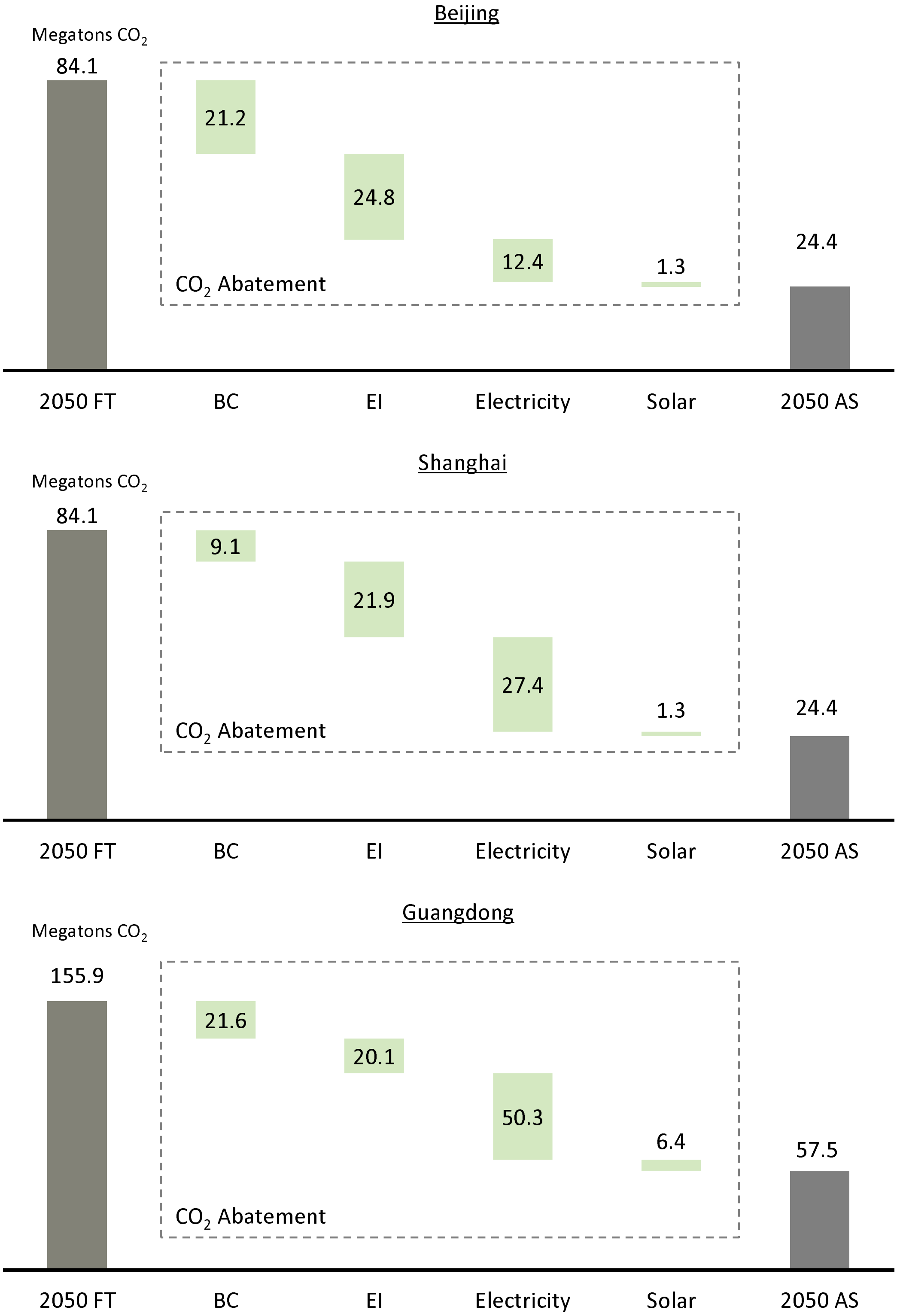


Figure 6.6 Breakdown of CO_2 reductions in 3 districts (year 2050, AS)

FT: Frozen technology AS: Abatement scenario

BC: Behavioral change EI: Equipment improvement

6.3 Marginal Abatement Cost

As the second part of the model outputs, estimated results of marginal abatement cost have been conducted by MAC sub-model. Figure 6.7 gives examples of the marginal abatement cost curve (MACC) in 3 districts.

The features of MACC differ from area to area due to the distinctive climate characters and energy consumption structure. In Beijing's case, implementation of eco-appliances appears to be the most expensive policy (1270.93 USD per ton). Despite the high-priced initial investment cost, energy savings contributed by eco-appliances are quite limit. The cost saving of electricity expense offers little to balance out the investment cost which leads directly to a stiff MAC. Regarding to cost-effectiveness of eco-appliances, MACCs of Shanghai and Guangdong resemble to Beijing's.

On the other hand, the other 2 policies that also need initial investment cost: thermal retrofit and high efficiency lighting have good performance on cost-efficiency. The investment costs are well compensated by money savings from energy expense. The implementation of thermal retrofit could be fulfilled at a -71.51 USD per ton MAC in Beijing and -529.02 USD per ton in Shanghai. The MACs of implementing high efficiency lighting are lower than 30 USD per ton in all 3 districts. One exception is thermal retrofit's MAC of Guangdong. In such a subtropical area with a heavy energy load of cooling system, thermal retrofit could not bring enough energy reduction. MAC of thermal retrofit unfortunately becomes the most costly efficiency policy in Guangdong. Although not being included in this study, instead of thermal retrofit advanced ventilation system would be more appreciate in the southern China.

As for behavioral changes policy, they all bring savings of energy expense at different amount levels. Therefore MACs range from -200 to -800 USD per ton. While the emission abatements from standby power saving and economy usage of DHW seem to be minor compare to economy usage of air-conditioning.

The 8 policies' average MACs of all 31 districts are illustrated in Figure 6.8. From the national MAC curve it appears that districts in hot summer cold winter area have lower MACs, while districts in cold / sever cold area have higher MACs.

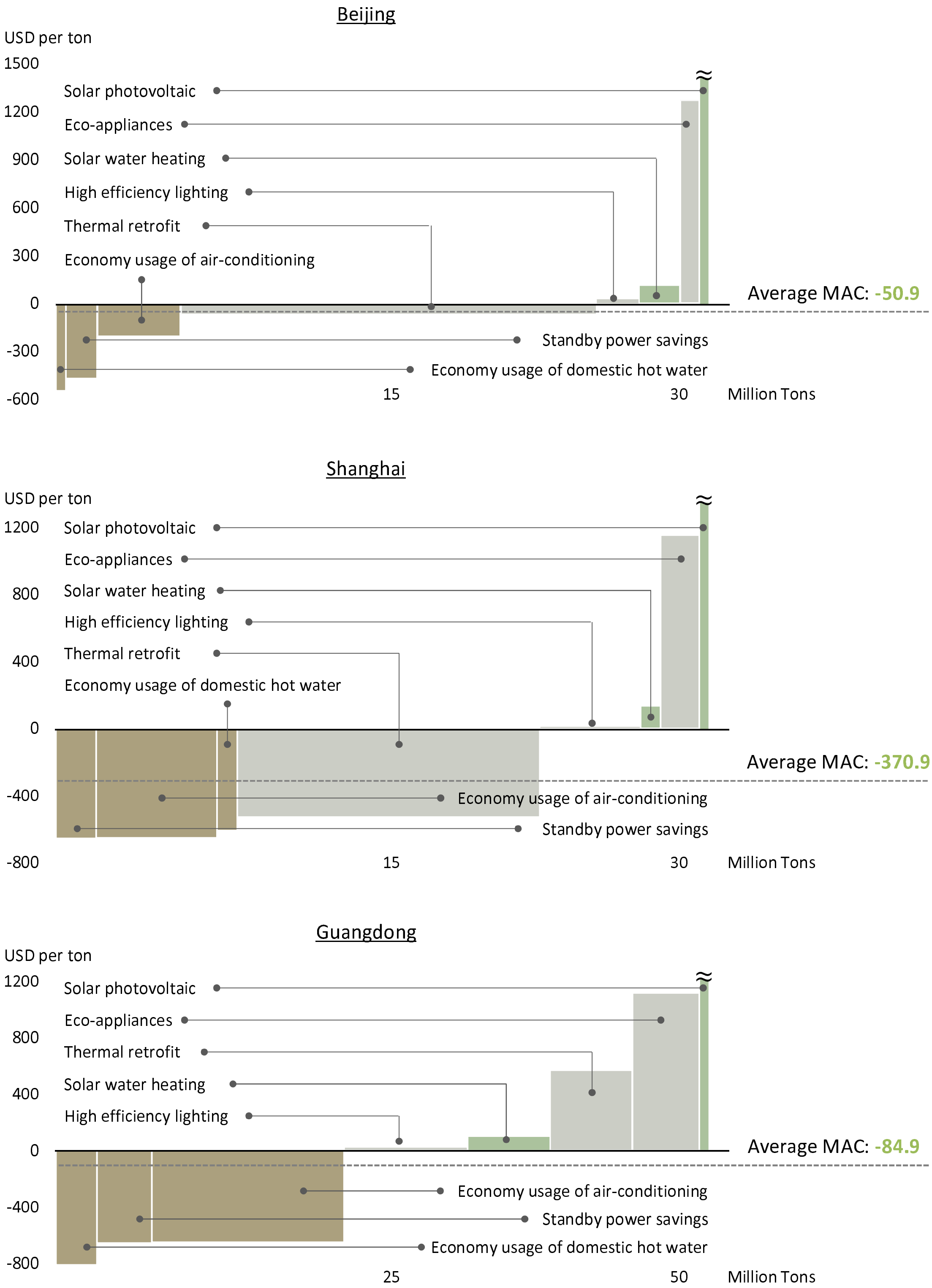


Figure 6.7 Marginal abatement cost curve in 3 districts

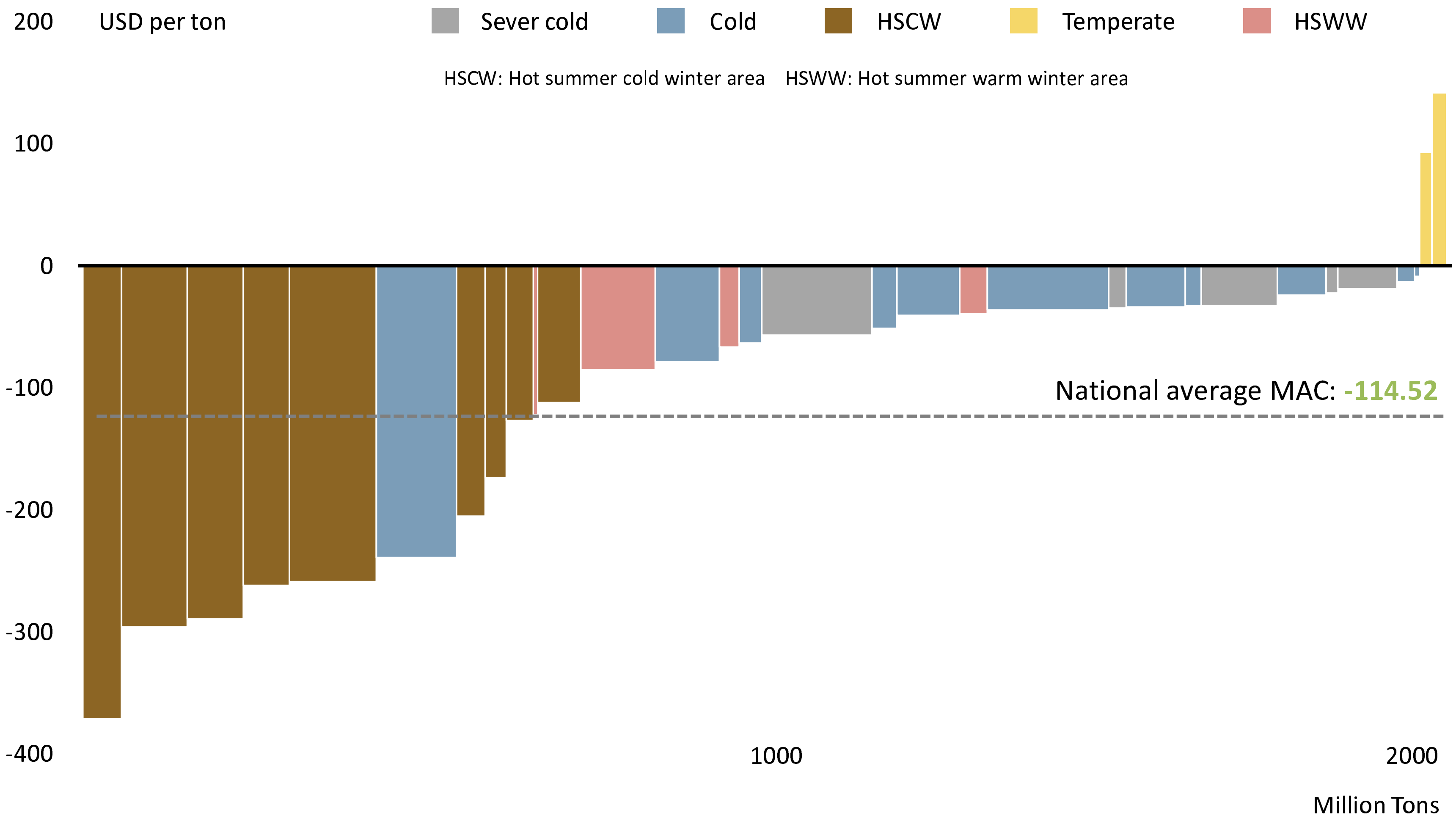


Figure 6.8 Marginal abatement cost curve of Chinese districts in average

6.4 Uncertainty Analysis

6.4.1 Uncertainty analysis of CO_2 abatement

During the past several years, increasing attention has been paid to the subject of managing some of the risk inherent in most projects. For the most part, risk has been interpreted as being unsure about project tack durations or costs, but uncertainty plagues all aspects of the work on projects and is presented in all stages of project life cycles (Hillier, 2011).

To apply risk analysis, one must assumptions about the probability distributions that characterize key parameters and variables associated with a decision and then use these to estimate the risk profiles or probability distributions of the outcomes of the decision. This can be done analytically but in this study the Monte Carlo simulation was applied. The simulation software Crystal Ball (CB) allows the decision to be represented by a mathematical model and then selects samples from the assumed distributions for each input. The software then plugs these inputs into the model and finds the outcomes of the decision.

The basic steps for doing Monte Carlo analysis are illustrated in Figure 6.9 (A. Boardman et al, 2006). First, specify probability distributions for all the important uncertain quantitative assumptions. In this case, penetration rate of each policy and working efficiency of each appliance were defined as normal distribution while investment costs of low-carbon technologies were defined as triangle distribution (ENAA, 2002; Kuzuki, 2010). Table 6.1 gives the specific settings of all parameters.

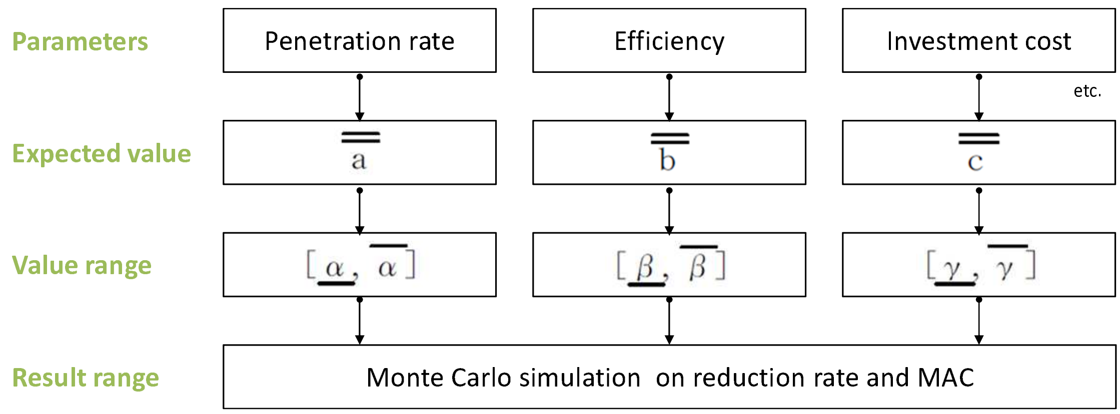
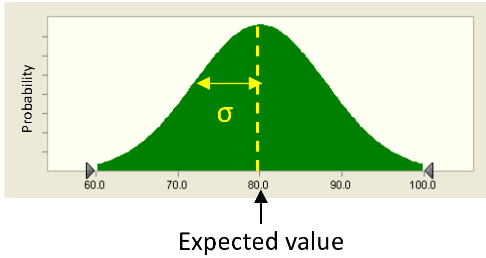
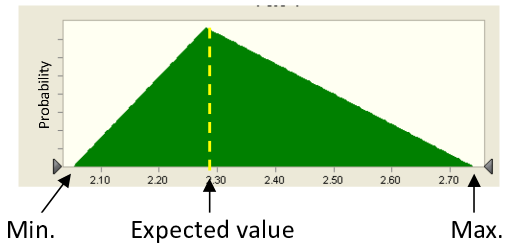


Figure 6.9 Basic steps of Monte Carlo simulation

Table 6.1 Distribution settings of parameters

Parameter	Expected Value	Standard Deviation σ	Value Range Max.	Value Range Min.	Distribution
Penetration rates of low-carbon policies					
Heating and cooling policy	80%	8%	100%	56%	
DHW policy	80%	8%	100%	56%	
House appliances policy	80%	8%	100%	56%	
Penetration rates of renewable energy					
Solar water heating	30%	3%	39%	21%	
Solar photovoltaic	2%	0.2%	2.6%	1.4%	
Appliances' efficiency					
Regional heating efficiency	39%	4%	51%	27%	
Heating COP	1.8	0.18	2.34	1.26	
Cooling COP	2.0	0.20	2.60	1.40	
DHW supply efficiency	70%	7%	91%	49%	
Reduction rate of electricity CO_2 intensity	60%	6%	78%	42%	
Investment cost of low-carbon technologies					
Thermal retrofit (USD/household)	1166	-	1399.2	1049.4	
High efficiency lighting (USD/household)	15	-	18	13.5	
Solar water heating (USD/household)	153	-	183.6	137.7	
Eco-refrigerator (USD/unit)	160	-	192	144	
Eco-television (USD/unit)	195	-	234	175.5	
Solar photovoltaic (USD/kW)	9600	-	11520	8640	





Section 6.1 gives a maximum abatement potential (100% percentiles). However, taking uncertainties of the efficiency policies' executions into account, the reduction rate of abatement scenario appears to be waving in a certain range. Figure 6.10 shows the results in the form of a frequency chart, a statistics table, and a percentiles table. Out of 1,000 trials, both the statistics table and percentiles table indicate that one trial had a reduction rate as 37% while another was as 51%. The frequency chart indicates that the reduction rate occurred most frequently during the 1,000 trials is close to 45.5%, but that many other rates up to 5% either less or more than this also occurred with considerable frequency. The mean reduction rate is 45%. (The mean standard error 0 reported at the bottom of the statistics table shows that the sample average of 45% from the 1,000 trials probably is extremely close to the true mean of the underlying probability distribution of reduction rate.)

Illustrated in Figure 6.11 are the 3 parameter inputs (assumption cells in CB) which have the most influential power over the estimates of CO_2 abatement. It is understandable that due to different structures of energy consumption, area with representative climatic characters have its distinctive sensitivity holders. In a regional heated area like Beijing, heating policies' penetration rate appears to be the most influential variable. For warm areas like Shanghai and Guangdong, reduction rate of electricity CO_2 intensity appears to be the most influential variable. Such influential variables should be put much effort into in order to achieve the expected CO_2 reduction rate.

The same uncertainty analysis was applied on 31 districts. Figure 6.12 shows the simulation resolution. Besides giving a possible range of reduction rate, the orange dots represent the mean values, which could be seen as a proper reduction mark for year 2050.

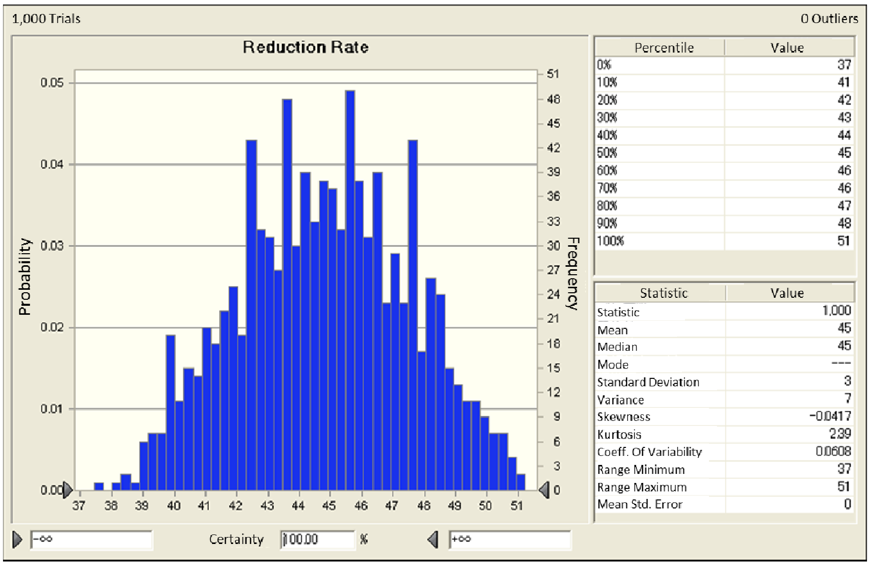


Figure 6.10 The frequency chart, statistics table, and percentiles table of Beijing's results

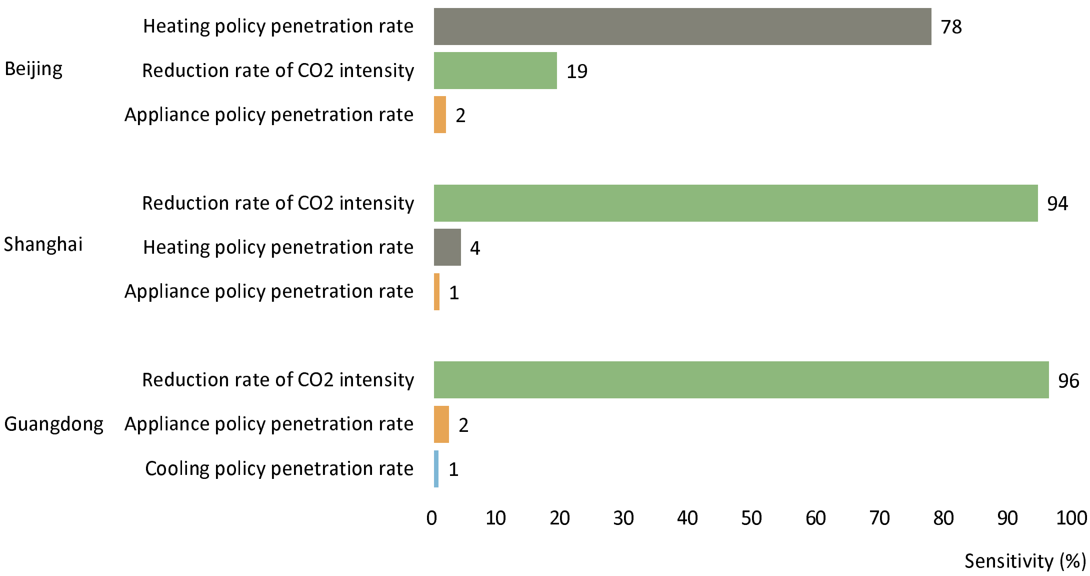


Figure 6.11 Sensitivity chart of uncertainty analysis (reduction rate)

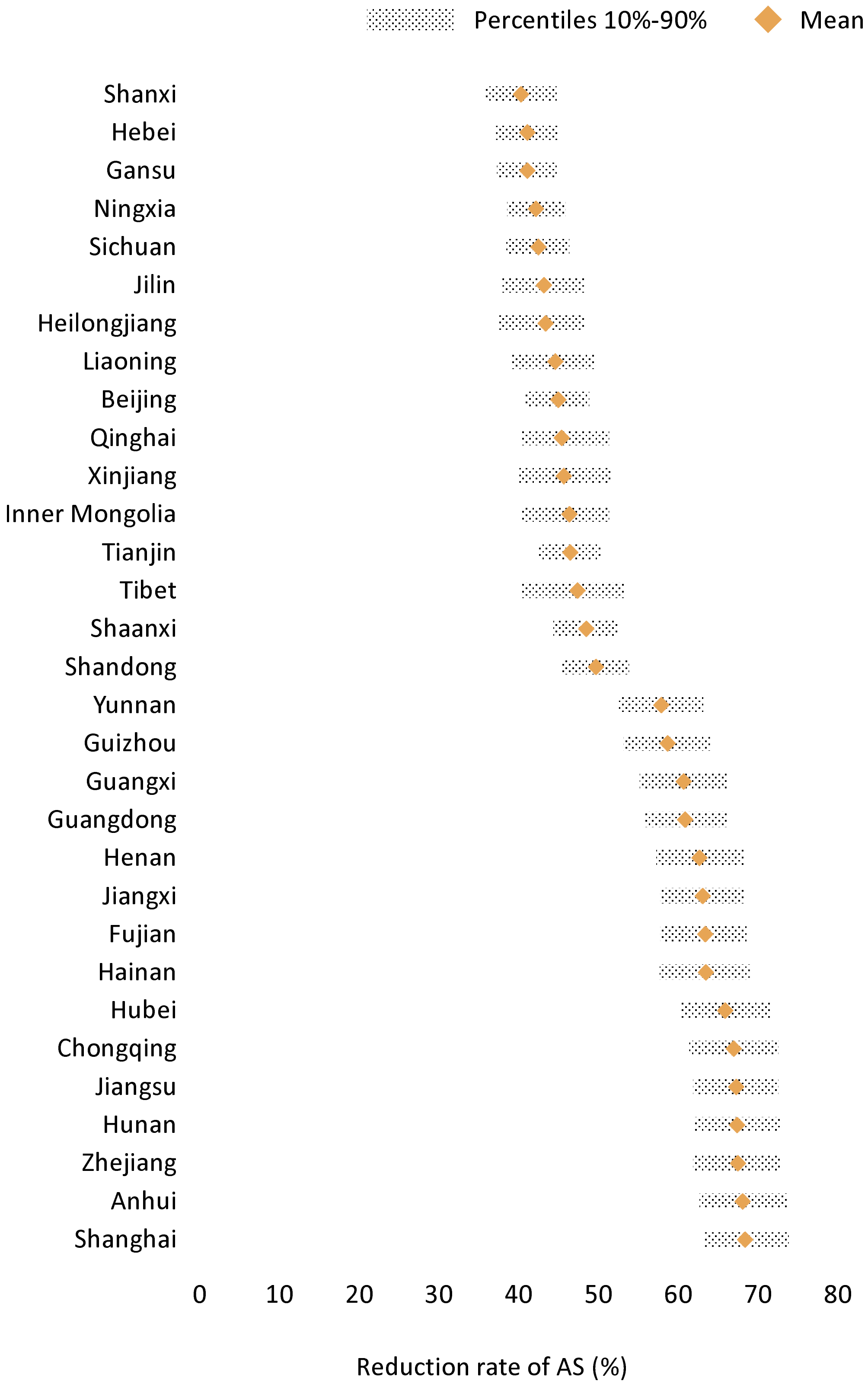


Figure 6.12 Possible range and mean value of emission reduction rate

6.4.2 Uncertainty analysis of marginal abatement cost

The MAC sub-model involves cost related parameter inputs that lead to projection of results of MAC. Therefore in uncertainty analysis of MAC, as assumption cells, initial investment cost of efficiency technologies, social discount rate of energy price and investment cost have been set up with normal distribution.

Figure 6.13 show the sensitivity chart of MAC uncertainty. A correlation coefficient between two variables measures the strength of the relationship between those variables. Thus, each correlation coefficient in Figure 6.13 measures how strongly that input value is influencing the marginal abatement cost. The higher the correlation coefficient, the stronger is this influence. Therefore, the parameter input with the highest correlation coefficients are those where the greatest effort should be made to minimalize the cost.

Figure 6.13 indicates that penetration rate of heating policy has a far higher correlation coefficient than the other in Beijing and Shanghai. The minus sensitivity value suggests that the larger penetration rate could bring lower average MAC. While in Guangdong and other warm areas reduction rate of CO_2 intensity shows a strong impact on average MAC. And the plus sensitivity value suggests that in the future, with CO2 intensity being improved, the cost of low-carbon policies could be more expensive. Figure 6.14 shows the national wild results of uncertainty analysis.

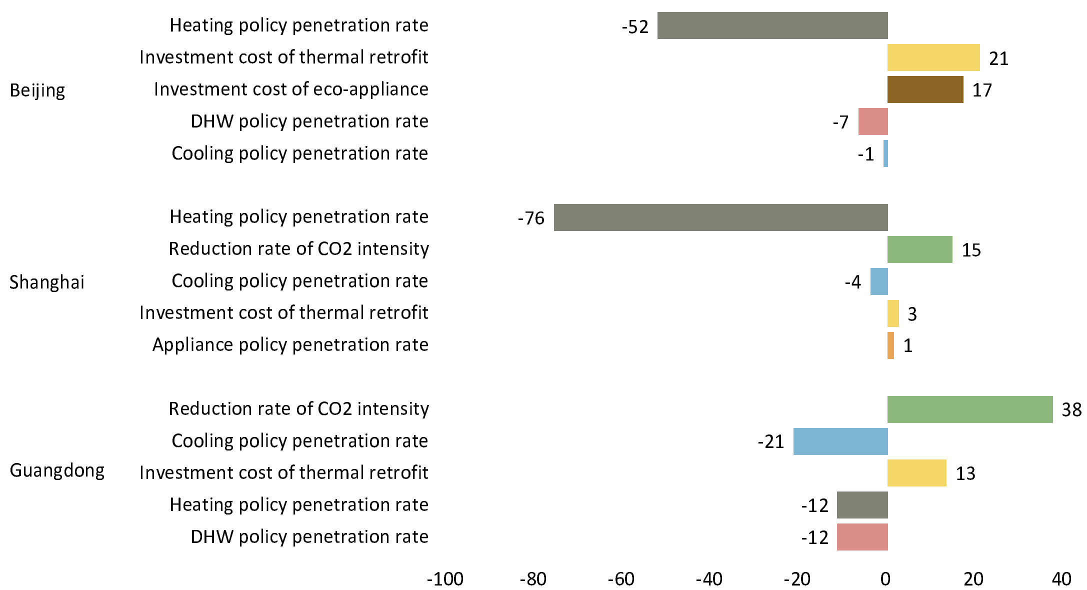


Figure 6.13 Sensitivity chart of uncertainty analysis (MAC)

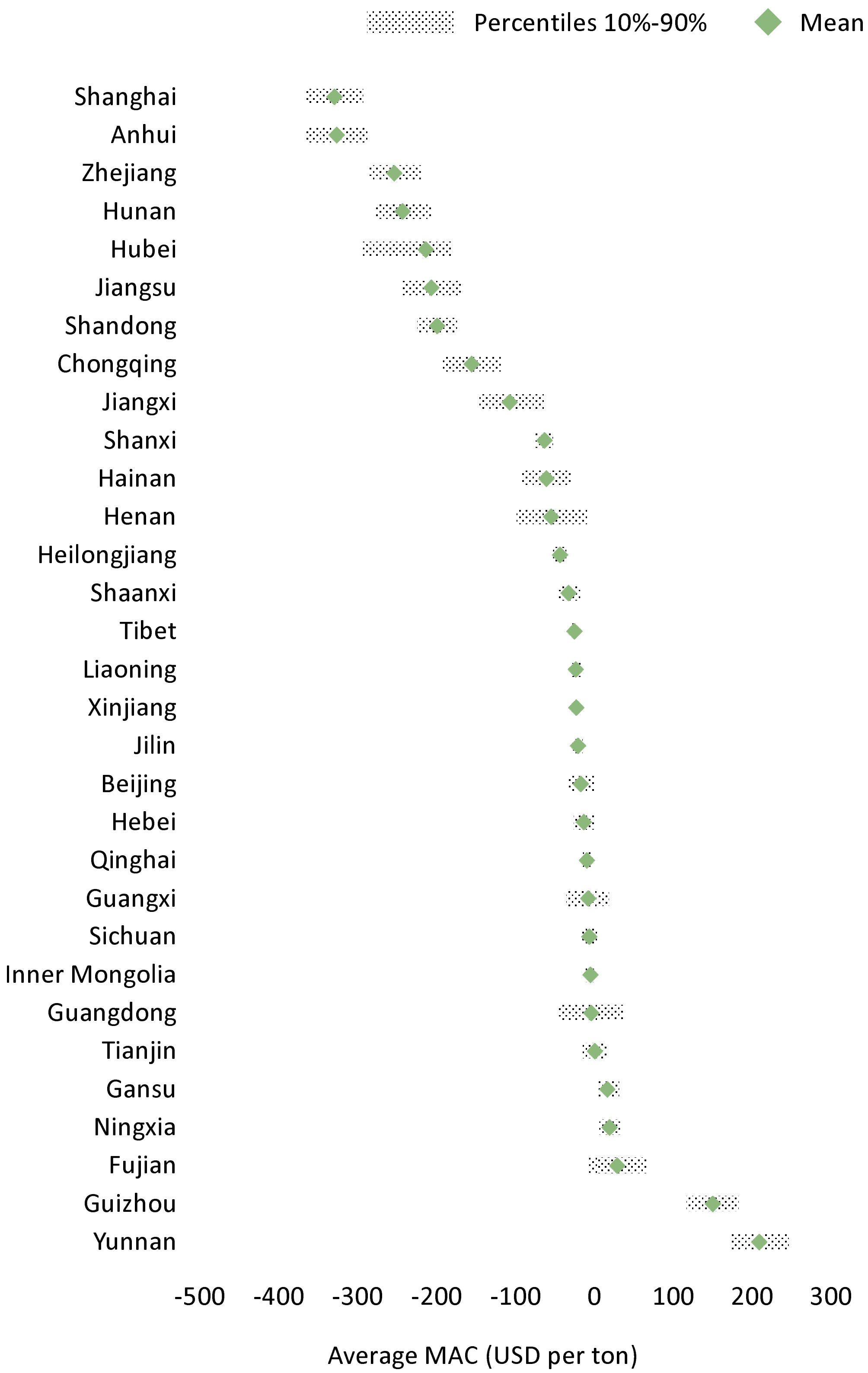


Figure 6.3 Possible range and mean value of MAC

6.5 Summary

This chapter first presented the estimated results of CO_2 emission and marginal abatement cost, and then presumed with uncertainty analysis.

In the national overview of CO_2 emission, for the northern cold area, central heating will still be the major energy consumer in the future, which means reference scenario will have larger contributions for emission reduction. While in the southern area efficient electricity generation is needed as well as the technology innovation of household appliances. Reduction rate of reference scenario gets smaller from north to south. The top 3 FT compared emission drops occur in Tibet (51.33%), Inner Mongolia (48.21%) and Xinjiang (47.98%). On the other hand, reduction rate of abatement scenario gets bigger from north to south. The top 3 FT compared emission drops occur in Shanghai (71.01%), Jiangsu (70.17%) and Zhejiang (70.15%).

In a cold area such like Beijing, equipment improvement that includes thermal retrofit appears to be contributing the major part (24.8 megatons in year 2050) of CO_2 reduction. On the other hand, efforts from electricity area are efficient in the area with a milder climate. Take Shanghai as an example, improvement of electricity intensity alone could bring 27.4 megatons of CO_2 abatement, which is almost half of the whole abatement amount. Behavioral changes contribute a respectively significant amount of CO_2 reduction in all 3 districts. The implementation of low carbon lifestyle will play an important role in the future.

For marginal abatement cost, thermal retrofit and high efficiency lighting have good performance on cost-efficiency, while implementation of eco-appliances appears to be rather expensive (1270.93 USD per ton in Beijing).

After getting primary results of CO_2 reduction rate and MAC, the uncertainty analysis has been applied using Monte Carlo simulation. First several variables have been setup with relative distributions, then both mean value and fluctuating range (percentiles 10% - 90%) have been conducted by the simulation.

Chapter 7

Conclusions

"A safe, environmentally sound, and economically viable energy pathway that will sustain human progress into the distant future is clearly imperative. It is also possible. But it will require new dimensions of political will and institutional cooperation to achieve it".

("Our Common Future", 1987)

CONTENTS

During the above 6 chapters the future vision of CO_2 emission from Chinese residential sector as well as the mitigation plan have been created and examined. This chapter gives the conclusion, and points out the future direction for the continuance of this research.

7.1 Conclusion and Discussion

Since 1990, China's economy has grown fourfold, resulting in more than a doubling of energy use. Strong energy efficiency improvements have helped to limit growth in energy use. But the rising dominance of coal in the country's energy mix has meant that energy-related carbon dioxide (CO_2) emissions have grown faster than energy consumption. Especially in the urban area, with the improvement of living standards, energy consumption and CO_2 emissions have increased significantly.

In order to cope with the energy issue and be prepared for the escalated energy crisis in the future, this study addressed the household energy end-users and evaluated the related efficiency policies. The previous researches that related to energy problem usually take China as a subject and overlook climatic difference and economic gap between districts. This study focused on 31 districts of mainland China and conducted evaluations on each district via a macro engineering model. The applied model consists of 3 sub-models. First the emission sub-model projects energy consumption and CO_2 emission through 2050 with a bottom-up approach. Secondly the scenario sub-model provides several efficiency policies that have been illustrated as 2 efficiency scenarios.

In this paper, the efficiency policies for Chinese residential buildings have been evaluated thoroughly about their effectiveness and possible impact to the future. During the evaluation process both climatic and civil characters of 31 districts were fully considered.

CO_2 emissions In year 2050, the CO_2 emissions in all Chinese districts see an aggressive increase without any mitigation plan. Reduction rate of reference scenario gets smaller from north to south. The top 3 FT compared emission drops occur in Tibet (51.33%), Inner Mongolia (48.21%) and Xinjiang (47.98%). On the other hand, reduction rate of abatement scenario gets bigger from north to south. The top 3 FT compared emission drops occur in Shanghai (71.01%), Jiangsu (70.17%) and Zhejiang (70.15%).

In a cold area such like Beijing, equipment improvement that includes thermal retrofit appears to be contributing the major part (19.3 megatons in year 2050) of CO_2 reduction. On the other hand, efforts from electricity area are efficient in the area with a milder climate. In the south area, equipment improvement appears to be extremely small, while efforts from electricity industry contributed more than half of the total reductions.

Marginal abatement cost The features of MACC differ from area to area due to the distinctive climate characters and energy consumption structure. In Beijing's case, implementation of eco-appliances appears to be the most expensive policy (1270.93 USD per ton).

On the other hand, the other 2 policies that also need initial investment cost: thermal retrofit and high efficiency lighting have good performance on cost-efficiency. The investment costs are well compensated by money savings from energy expense. The implementation of thermal retrofit could be fulfilled at a -71.51 USD per ton MAC in Beijing and -529.02 USD per ton in Shanghai. The MACs of implementing high efficiency lighting are lower than 30 USD per ton in all 3 districts. One exception is thermal retrofit's MAC of Guangdong. MAC of thermal retrofit appears to be the most costly efficiency policy in Guangdong.

Behavioral changes policies all bring savings of energy expense at different amount levels. Therefore MACs range from 200 to 800 USD per ton.

Policy suggestion With a high MAC in all the districts, implementation of eco-appliances is obviously not a preferable choice for efficiency policies. On the other hand, the other 2 policies that also need initial investment cost: thermal retrofit and high efficiency lighting have good performance on cost-efficiency. The investment costs are well compensated by money savings from energy expense. However thermal retrofit in HSWW (hot summer warm winter) area may not be the best choice simply because a heavy energy load of cooling system in such a climate area makes the energy reduction brought by thermal retrofit are not significant enough.

As for behavioral changes policy, they all bring savings of energy expense at different amount levels. While the actual problem with behavioral changes is that its profits are not wildly understood by the public, which makes it an important task to dispatch the information.

7.2 Further Work

During the database constructing, necessary information of both social and engineering side have been gathered as much as possible. However, there is still quite a few items remain assumptions due to a lack of information sources. These items were later modified during the model calibration process, but it is preferable to replace them with assured reference. To make a more provable case, the accuracy of the evaluation model needs to be improved.

While conducting this research, due to the limited time period and human resource, the evaluation subject has been narrowed down to the urban area, despite the fact that rural household holds about 70% of the total residential energy consumption in China. The applied bottom-up model has been constructed in a fairly opened way. Therefore it is possible to switch the parameter inputs of household and other basic information with rural index and make it suitable for the rural area's projection.

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Appendix

Appendix 1. Regional household number projection through 2050 (million)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Heilongjiang	6.34	6.80	7.12	7.87	8.58	9.18	9.65	9.96	10.11	10.12	9.95
Inner Mongolia	3.06	3.85	4.33	4.80	5.23	5.59	5.88	6.10	6.24	6.31	6.27
Qinghai	0.46	0.58	0.78	0.87	0.94	1.01	1.06	1.11	1.16	1.20	1.22
Tibet	0.10	0.15	0.69	0.75	0.80	0.85	0.89	0.92	0.95	0.98	0.99
Xinjiang	1.77	2.15	3.75	4.15	4.51	4.82	5.07	5.29	5.51	5.70	5.81
Jilin	4.09	4.52	4.90	5.42	5.91	6.32	6.64	6.84	6.93	6.90	6.76
Liaoning	8.02	8.48	8.74	9.67	10.54	11.27	11.84	12.19	12.31	12.23	11.93
Beijing	3.57	4.66	5.00	5.53	6.03	6.45	6.78	7.01	7.13	7.16	7.06
Tianjin	2.33	2.63	3.21	3.55	3.87	4.14	4.35	4.50	4.59	4.61	4.55
Hebei	5.23	7.76	10.14	11.22	12.23	13.08	13.78	14.37	14.88	15.28	15.47
Shandong	11.29	14.30	13.80	15.23	16.55	17.65	18.52	19.17	19.61	19.85	19.78
Ningxia	0.48	0.70	0.97	1.07	1.17	1.25	1.31	1.37	1.43	1.48	1.51
Sichuan	6.70	9.18	10.62	11.75	12.81	13.70	14.40	14.92	15.24	15.37	15.26
Shaanxi	3.26	4.24	5.50	6.09	6.63	7.10	7.46	7.75	7.95	8.06	8.04
Shanxi	3.18	4.17	5.28	5.85	6.37	6.82	7.17	7.45	7.66	7.79	7.80
Gansu	1.65	2.12	2.88	3.19	3.48	3.72	3.92	4.09	4.24	4.36	4.43
Shanghai	5.24	5.91	5.70	6.31	6.88	7.36	7.74	8.01	8.16	8.22	8.13
Anhui	5.10	7.16	8.65	9.57	10.44	11.17	11.76	12.26	12.71	13.06	13.23
Henan	6.33	8.40	11.99	13.27	14.46	15.47	16.28	16.93	17.45	17.79	17.87
Jiangsu	9.97	12.77	14.40	15.93	17.36	18.58	19.53	20.24	20.71	20.94	20.83
Chongqing	3.18	4.45	4.94	5.47	5.96	6.38	6.71	6.96	7.13	7.22	7.19
Hunan	6.63	7.41	9.27	10.26	11.19	11.97	12.60	13.15	13.63	14.00	14.18
Zhejiang	7.61	9.94	10.05	11.12	12.13	12.97	13.64	14.16	14.52	14.72	14.70
Hubei	6.91	7.98	8.82	9.76	10.64	11.38	11.97	12.40	12.68	12.82	12.74
Jiangxi	3.05	4.84	6.41	6.83	7.23	7.59	7.88	8.12	8.34	8.48	8.46
Yunnan	2.69	3.65	5.21	5.76	6.28	6.72	7.08	7.38	7.63	7.82	7.90
Guizhou	2.27	2.90	3.80	4.21	4.59	4.91	5.17	5.40	5.61	5.78	5.87
Guangxi	3.32	4.62	6.38	7.06	7.70	8.24	8.67	9.07	9.43	9.74	9.92
Guangdong	11.59	15.83	20.48	22.66	24.71	26.43	27.82	28.95	29.86	30.50	30.69
Fujian	4.09	5.57	6.25	6.91	7.54	8.06	8.49	8.84	9.13	9.35	9.43
Hainan	0.85	0.97	1.42	1.57	1.72	1.84	1.93	2.02	2.11	2.18	2.23

Appendix 2. Regional household size projection through 2050 (person)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Heilongjiang	3.23	2.97	2.84	2.77	2.71	2.67	2.64	2.62	2.59	2.57	2.56
Inner Mongolia	3.31	2.91	2.90	2.83	2.79	2.75	2.73	2.71	2.69	2.67	2.66
Qinghai	3.95	3.67	3.57	3.49	3.44	3.39	3.36	3.33	3.31	3.29	3.27
Tibet	4.77	5.03	4.57	4.43	4.34	4.27	4.22	4.18	4.14	4.11	4.08
Xinjiang	3.68	3.47	3.48	3.42	3.39	3.36	3.35	3.33	3.32	3.31	3.30
Jilin	3.32	3.14	3.01	2.94	2.90	2.87	2.84	2.82	2.80	2.79	2.77
Liaoning	3.15	2.92	2.83	2.76	2.71	2.67	2.64	2.62	2.60	2.58	2.56
Beijing	2.91	2.70	2.66	2.58	2.52	2.47	2.43	2.39	2.36	2.33	2.30
Tianjin	3.09	2.92	3.26	3.21	3.18	3.15	3.13	3.12	3.10	3.09	3.08
Hebei	3.57	3.32	3.26	3.21	3.18	3.15	3.13	3.12	3.10	3.09	3.08
Shandong	3.21	2.90	2.86	2.81	2.78	2.76	2.74	2.72	2.70	2.69	2.68
Ningxia	3.80	3.58	3.53	3.48	3.45	3.42	3.40	3.38	3.37	3.36	3.35
Sichuan	3.32	2.95	2.93	2.84	2.78	2.73	2.69	2.66	2.64	2.61	2.59
Shaanxi	3.57	3.26	3.11	3.00	2.92	2.86	2.81	2.77	2.74	2.71	2.68
Shanxi	3.62	3.38	3.24	3.14	3.07	3.02	2.98	2.94	2.91	2.88	2.86
Gansu	3.97	3.67	3.70	3.62	3.57	3.52	3.48	3.45	3.42	3.39	3.37
Shanghai	2.80	2.65	2.79	2.65	2.52	2.40	2.28	2.17	2.07	1.97	1.87
Anhui	3.51	3.02	3.39	3.22	3.06	2.92	2.77	2.64	2.51	2.39	2.27
Henan	3.65	3.42	3.34	3.30	3.27	3.25	3.23	3.22	3.20	3.19	3.18
Jiangsu	3.23	2.91	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Chongqing	3.21	2.83	2.73	2.60	2.51	2.45	2.39	2.35	2.31	2.28	2.25
Hunan	3.44	3.14	3.26	3.32	3.36	3.38	3.40	3.42	3.43	3.44	3.45
Zhejiang	2.99	2.73	2.80	2.78	2.77	2.76	2.75	2.74	2.74	2.74	2.73
Hubei	3.51	3.08	3.03	2.97	2.92	2.89	2.86	2.84	2.82	2.80	2.79
Jiangxi	3.76	3.29	3.62	3.74	3.82	3.87	3.92	3.95	3.98	4.01	4.03
Yunnan	3.73	3.59	3.54	3.46	3.41	3.37	3.34	3.32	3.29	3.27	3.26
Guizhou	3.71	3.45	3.63	3.69	3.72	3.75	3.77	3.78	3.80	3.81	3.82
Guangxi	3.81	3.38	3.62	3.69	3.73	3.76	3.79	3.81	3.83	3.84	3.85
Guangdong	3.69	3.40	3.26	3.12	3.03	2.96	2.90	2.86	2.82	2.78	2.75
Fujian	3.53	2.99	2.99	2.93	2.89	2.86	2.83	2.81	2.80	2.78	2.77
Hainan	4.06	3.84	3.77	3.70	3.65	3.61	3.58	3.56	3.54	3.52	3.50

Appendix 3. Regional projections of floor area (million square meters)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Heilongjiang	122.0	311.5	336.8	385.9	430.5	468.7	499.5	521.6	534.9	539.9	535.0
Inner Mongolia	45.6	152.6	177.7	201.9	224.1	243.0	258.3	270.1	278.6	283.5	283.7
Qinghai	6.9	23.1	34.4	38.8	42.9	46.4	49.3	51.9	54.4	56.5	57.9
Tibet	3.0	8.0	50.3	57.8	64.4	70.0	74.7	78.9	82.7	86.0	88.6
Xinjiang	37.1	107.1	210.3	242.2	271.0	295.6	316.1	334.9	352.7	368.3	379.2
Jilin	74.1	177.9	195.0	219.1	241.3	260.2	275.1	285.1	289.9	290.2	285.1
Liaoning	171.7	314.8	382.0	436.6	486.4	528.9	562.8	585.6	597.0	598.0	587.6
Beijing	77.8	202.5	204.9	220.3	235.3	247.8	257.1	262.8	264.9	263.6	258.1
Tianjin	43.0	98.3	113.3	121.8	130.4	137.6	143.1	146.6	148.2	147.9	145.3
Hebei	101.8	365.6	456.2	497.2	536.8	570.2	597.0	619.8	639.5	654.2	660.2
Shandong	176.4	489.6	513.4	579.0	636.6	684.6	722.6	751.8	772.2	784.2	784.0
Ningxia	10.1	34.9	45.3	46.5	48.1	49.4	50.3	51.1	51.9	52.4	52.4
Sichuan	97.1	390.0	436.1	454.5	474.8	491.4	502.7	508.5	508.9	504.0	492.0
Shaanxi	47.2	152.6	189.3	198.8	208.7	216.7	222.4	225.9	227.4	226.7	223.0
Shanxi	63.0	200.6	399.7	487.3	561.5	624.3	676.2	719.2	754.0	779.7	792.4
Gansu	33.8	106.2	140.1	148.1	156.3	162.9	167.9	172.0	175.6	178.0	178.1
Shanghai	120.3	266.0	299.4	350.3	396.1	435.5	467.8	492.6	509.9	519.9	520.6
Anhui	61.5	216.9	235.7	238.3	243.8	248.3	250.8	252.6	253.7	253.3	250.1
Henan	106.3	396.4	432.1	432.6	437.3	439.8	438.9	435.5	430.2	422.0	409.0
Jiangsu	152.1	530.9	674.4	769.1	853.8	925.4	983.0	1027.2	1058.4	1076.2	1076.3
Chongqing	46.5	161.8	210.0	240.5	268.2	292.0	311.3	326.5	337.8	344.9	346.4
Hunan	96.3	317.1	421.5	477.5	527.9	570.5	605.4	635.7	662.3	683.5	695.2
Zhejiang	119.9	522.6	508.0	592.5	665.2	726.3	775.9	815.3	845.0	864.5	869.9
Hubei	151.7	306.5	356.3	400.7	441.6	476.4	504.4	525.5	540.2	548.1	547.1
Jiangxi	46.8	196.0	233.2	224.8	222.1	220.5	218.6	216.7	214.8	211.6	204.9
Yunnan	38.2	158.4	195.9	199.1	204.6	209.0	211.7	213.5	214.6	214.2	211.4
Guizhou	27.7	89.7	115.9	127.3	138.0	147.0	154.2	160.6	166.3	170.9	173.3
Guangxi	47.6	199.2	239.7	244.3	251.5	257.4	261.3	264.7	267.8	269.6	268.4
Guangdong	155.3	702.8	853.9	884.8	920.5	949.3	969.0	982.5	990.4	990.8	978.7
Fujian	57.8	226.1	286.2	327.5	365.2	397.4	424.0	446.6	465.8	480.6	488.3
Hainan	20.4	38.0	50.9	52.7	54.9	56.7	58.0	59.2	60.4	61.3	61.5

Appendix 4. Regional projections of household appliances (ownership per household)

		2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Heilong-jiang	Washing Machine	0.83	0.92	0.94	0.95	0.96	0.97	0.98	0.98	0.99	0.99	0.99
	Refrigerator	0.66	0.78	0.87	0.91	0.94	0.96	0.98	0.99	1.00	1.01	1.02
	TV Set (color)	1.02	1.12	1.17	1.19	1.20	1.21	1.22	1.23	1.24	1.24	1.25
	Computer	0.05	0.26	0.45	0.65	0.85	1.04	1.23	1.42	1.60	1.78	1.96
	Stereo System	0.16	0.13	0.22	0.23	0.24	0.25	0.25	0.26	0.26	0.26	0.27
	Micro-wave	0.06	0.29	0.36	0.41	0.45	0.48	0.50	0.52	0.54	0.56	0.57
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.14	0.15	0.17	0.18	0.19	0.19	0.20	0.20	0.20	0.20	0.21
Inner Mongolia	Washing Machine	0.91	0.95	0.95	0.97	0.97	0.98	0.99	0.99	1.00	1.00	1.01
	Refrigerator	0.70	0.86	0.93	0.98	1.03	1.06	1.09	1.12	1.14	1.16	1.18
	TV Set (color)	1.07	1.13	1.16	1.19	1.21	1.23	1.25	1.27	1.28	1.29	1.30
	Computer	0.03	0.23	0.41	0.68	0.99	1.34	1.74	2.18	2.65	3.16	3.70
	Stereo System	0.12	0.14	0.17	0.17	0.18	0.19	0.19	0.20	0.20	0.20	0.21
	Micro-wave	0.05	0.26	0.33	0.37	0.41	0.43	0.46	0.48	0.50	0.51	0.53
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.09	0.12	0.12	0.13	0.13	0.14	0.14	0.14	0.15	0.15	0.15
Qinghai	Washing Machine	1.01	0.98	1.02	1.03	1.04	1.05	1.05	1.06	1.06	1.06	1.07
	Refrigerator	0.80	0.81	0.90	0.94	0.98	1.01	1.03	1.05	1.07	1.09	1.10
	TV Set (color)	1.12	1.12	1.20	1.23	1.25	1.27	1.28	1.29	1.31	1.32	1.33
	Computer	0.02	0.22	0.38	0.62	0.92	1.25	1.62	2.03	2.48	2.96	3.47
	Stereo System	0.22	0.21	0.25	0.26	0.28	0.29	0.30	0.31	0.32	0.32	0.33
	Micro-wave	0.07	0.38	0.48	0.55	0.60	0.64	0.67	0.70	0.73	0.75	0.77
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.05	0.08	0.09	0.09	0.10	0.10	0.11	0.11	0.11	0.11	0.11
Tibet	Washing Machine	1.00	0.95	0.96	0.98	0.99	1.00	1.00	1.01	1.01	1.02	1.02
	Refrigerator	0.74	0.88	0.93	0.97	0.99	1.02	1.03	1.05	1.06	1.07	1.08
	TV Set (color)	1.20	1.35	1.38	1.41	1.43	1.45	1.46	1.47	1.48	1.49	1.50
	Computer	0.01	0.19	0.45	0.75	1.10	1.49	1.91	2.36	2.84	3.35	3.89
	Stereo System	0.24	0.32	0.36	0.38	0.39	0.40	0.41	0.41	0.42	0.43	0.43
	Micro-wave	0.03	0.34	0.39	0.45	0.50	0.53	0.56	0.59	0.61	0.63	0.65
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Xinjiang	Washing Machine	0.95	0.89	1.00	1.02	1.03	1.04	1.05	1.05	1.06	1.07	1.07

		2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Xinjiang	Refrigerator	0.82	0.80	0.89	0.92	0.94	0.96	0.97	0.99	1.00	1.01	1.02
	TV Set (color)	1.02	1.06	1.11	1.13	1.15	1.16	1.18	1.19	1.20	1.21	1.21
	Computer	0.06	0.24	0.48	0.81	1.21	1.67	2.19	2.76	3.39	4.08	4.81
	Stereo System	0.18	0.16	0.21	0.23	0.24	0.24	0.25	0.26	0.26	0.27	0.27
	Micro-wave	0.05	0.20	0.34	0.52	0.71	0.92	1.14	1.38	1.62	1.88	2.14
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.17	0.16	0.19	0.19	0.19	0.19	0.20	0.20	0.20	0.20	0.20
Jilin	Washing Machine	0.90	0.97	0.97	0.99	1.00	1.00	1.01	1.02	1.02	1.03	1.03
	Refrigerator	0.69	0.85	0.89	0.94	0.98	1.01	1.03	1.06	1.08	1.10	1.11
	TV Set (color)	1.07	1.27	1.27	1.32	1.35	1.38	1.41	1.43	1.45	1.47	1.49
	Computer	0.05	0.30	0.54	0.93	1.39	1.94	2.56	3.25	4.01	4.84	5.73
	Stereo System	0.15	0.14	0.19	0.19	0.20	0.21	0.21	0.22	0.22	0.23	0.23
	Micro-wave	0.07	0.36	0.41	0.47	0.51	0.55	0.58	0.61	0.63	0.65	0.67
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.13	0.16	0.18	0.19	0.20	0.21	0.21	0.22	0.22	0.23	0.23
Liaoning	Washing Machine	0.87	0.88	0.91	0.92	0.92	0.93	0.93	0.94	0.94	0.94	0.94
	Refrigerator	0.81	0.88	0.95	0.98	0.99	1.01	1.02	1.03	1.04	1.04	1.05
	TV Set (color)	1.14	1.22	1.26	1.30	1.33	1.36	1.38	1.40	1.42	1.43	1.44
	Computer	0.06	0.33	0.62	1.02	1.49	2.02	2.62	3.28	3.99	4.75	5.56
	Stereo System	0.18	0.22	0.26	0.27	0.29	0.30	0.31	0.32	0.33	0.33	0.34
	Micro-wave	0.12	0.42	0.55	0.62	0.67	0.72	0.75	0.78	0.81	0.84	0.86
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.23	0.22	0.25	0.26	0.26	0.26	0.26	0.27	0.27	0.27	0.27
Beijing	Washing Machine	1.03	1.05	1.09	1.11	1.13	1.14	1.15	1.16	1.17	1.17	1.18
	Refrigerator	1.07	1.04	1.09	1.11	1.12	1.13	1.14	1.15	1.15	1.16	1.16
	TV Set (color)	1.46	1.53	1.60	1.65	1.69	1.72	1.75	1.77	1.79	1.81	1.83
	Computer	0.32	0.89	1.16	1.55	1.92	2.29	2.66	3.03	3.39	3.74	4.10
	Stereo System	0.30	0.37	0.41	0.44	0.46	0.48	0.50	0.51	0.53	0.54	0.55
	Micro-wave	0.58	0.89	1.00	1.09	1.17	1.22	1.27	1.31	1.35	1.38	1.41
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.25	0.40	0.44	0.47	0.50	0.52	0.53	0.55	0.56	0.57	0.58
Tianjin	Washing Machine	0.98	0.96	1.00	1.01	1.02	1.02	1.03	1.03	1.04	1.04	1.04
	Refrigerator	1.00	0.98	1.06	1.08	1.10	1.11	1.12	1.13	1.14	1.14	1.15
	TV Set (color)	1.32	1.36	1.38	1.42	1.45	1.47	1.49	1.50	1.52	1.53	1.54
	Computer	0.16	0.51	0.80	1.16	1.53	1.92	2.33	2.74	3.17	3.61	4.06

		2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Tianjin	Stereo System	0.19	0.29	0.29	0.31	0.33	0.34	0.36	0.37	0.37	0.38	0.39
	Micro-wave	0.31	0.74	0.86	0.97	1.05	1.12	1.18	1.23	1.27	1.31	1.34
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.21	0.25	0.26	0.27	0.28	0.28	0.29	0.29	0.30	0.30	0.30
Hebei	Washing Machine	0.93	0.96	1.02	1.04	1.06	1.07	1.07	1.08	1.09	1.09	1.10
	Refrigerator	0.84	0.92	0.98	1.01	1.02	1.03	1.04	1.05	1.05	1.06	1.07
	TV Set (color)	1.12	1.24	1.30	1.32	1.33	1.34	1.35	1.36	1.37	1.38	1.38
	Computer	0.07	0.38	0.65	0.95	1.24	1.53	1.81	2.10	2.37	2.65	2.92
	Stereo System	0.18	0.23	0.27	0.29	0.30	0.31	0.32	0.32	0.33	0.33	0.34
	Micro-wave	0.10	0.40	0.51	0.58	0.63	0.67	0.70	0.73	0.75	0.77	0.79
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.10	0.13	0.15	0.15	0.16	0.16	0.17	0.17	0.17	0.17	0.18
Shandong	Washing Machine	0.89	0.93	0.95	0.96	0.96	0.97	0.97	0.98	0.98	0.98	0.99
	Refrigerator	0.87	0.91	0.98	1.01	1.02	1.04	1.05	1.06	1.06	1.07	1.08
	TV Set (color)	1.15	1.18	1.21	1.22	1.23	1.23	1.24	1.24	1.24	1.24	1.25
	Computer	0.10	0.46	0.77	1.05	1.32	1.56	1.80	2.03	2.25	2.46	2.67
	Stereo System	0.21	0.22	0.24	0.25	0.25	0.26	0.26	0.26	0.26	0.27	0.27
	Micro-wave	0.16	0.43	0.52	0.58	0.62	0.66	0.69	0.71	0.73	0.75	0.76
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.16	0.17	0.19	0.20	0.21	0.21	0.21	0.22	0.22	0.22	0.22
Ningxia	Washing Machine	0.87	0.90	0.96	0.97	0.98	0.99	1.00	1.00	1.01	1.01	1.01
	Refrigerator	0.80	0.79	0.85	0.88	0.91	0.93	0.95	0.97	0.98	0.99	1.00
	TV Set (color)	1.12	1.09	1.18	1.20	1.22	1.23	1.24	1.26	1.26	1.27	1.28
	Computer	0.02	0.23	0.40	0.67	0.98	1.34	1.74	2.19	2.67	3.18	3.74
	Stereo System	0.22	0.22	0.22	0.23	0.24	0.25	0.26	0.27	0.27	0.28	0.28
	Micro-wave	0.07	0.31	0.36	0.41	0.45	0.49	0.52	0.54	0.56	0.58	0.60
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.08	0.08	0.06	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04
Sichuan	Washing Machine	0.91	0.98	1.01	1.03	1.04	1.05	1.05	1.06	1.07	1.07	1.08
	Refrigerator	0.81	0.93	0.94	0.96	0.98	0.99	1.00	1.01	1.02	1.03	1.03
	TV Set (color)	1.19	1.39	1.40	1.44	1.47	1.50	1.52	1.54	1.56	1.57	1.58
	Computer	0.08	0.32	0.54	0.81	1.10	1.40	1.73	2.06	2.41	2.78	3.15
	Stereo System	0.25	0.30	0.31	0.33	0.34	0.35	0.36	0.36	0.37	0.38	0.38
	Micro-wave	0.15	0.43	0.50	0.56	0.61	0.66	0.69	0.72	0.75	0.77	0.79
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

		2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Sichuan	Vacuum Cleaner	0.05	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08
Shaanxi	Washing Machine	0.93	0.98	0.98	0.98	0.99	1.00	1.00	1.01	1.01	1.01	1.02
	Refrigerator	0.72	0.83	0.89	0.93	0.95	0.98	1.00	1.01	1.03	1.04	1.06
	TV Set (color)	1.14	1.29	1.31	1.35	1.39	1.42	1.44	1.46	1.48	1.50	1.51
	Computer	0.07	0.28	0.62	1.06	1.59	2.22	2.93	3.73	4.60	5.56	6.59
	Stereo System	0.17	0.23	0.26	0.29	0.31	0.32	0.34	0.35	0.36	0.37	0.38
	Micro-wave	0.08	0.35	0.45	0.51	0.56	0.60	0.63	0.66	0.69	0.71	0.73
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.05	0.07	0.07	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09
Shanxi	Washing Machine	0.93	1.00	0.98	0.98	0.99	1.00	1.00	1.01	1.01	1.01	1.02
	Refrigerator	0.76	0.87	0.90	0.95	0.98	1.01	1.03	1.05	1.07	1.09	1.10
	TV Set (color)	1.07	1.14	1.17	1.20	1.22	1.24	1.26	1.27	1.29	1.30	1.31
	Computer	0.06	0.30	0.52	0.83	1.19	1.58	2.02	2.49	2.99	3.52	4.09
	Stereo System	0.17	0.17	0.19	0.20	0.21	0.22	0.22	0.23	0.23	0.24	0.24
	Micro-wave	0.05	0.26	0.29	0.33	0.36	0.39	0.41	0.43	0.45	0.46	0.48
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.07	0.06	0.09	0.09	0.10	0.10	0.10	0.11	0.11	0.11	0.11
Gansu	Washing Machine	0.97	0.98	1.00	1.01	1.02	1.03	1.03	1.04	1.04	1.04	1.04
	Refrigerator	0.73	0.89	0.93	0.98	1.02	1.06	1.09	1.11	1.13	1.15	1.17
	TV Set (color)	1.21	1.18	1.33	1.37	1.41	1.44	1.46	1.48	1.50	1.52	1.54
	Computer	0.05	0.23	0.44	0.63	0.84	1.06	1.29	1.53	1.78	2.03	2.30
	Stereo System	0.25	0.27	0.35	0.38	0.41	0.42	0.44	0.45	0.46	0.47	0.47
	Micro-wave	0.07	0.28	0.32	0.37	0.41	0.44	0.46	0.49	0.50	0.52	0.54
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.05	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09
Shanghai	Washing Machine	0.93	0.97	1.00	1.02	1.03	1.05	1.06	1.07	1.08	1.09	1.09
	Refrigerator	1.02	1.04	1.04	1.05	1.05	1.06	1.06	1.06	1.06	1.07	1.07
	TV Set (color)	1.47	1.77	1.85	1.94	2.01	2.07	2.12	2.17	2.20	2.24	2.27
	Computer	0.26	0.81	1.26	1.78	2.30	2.84	3.40	3.96	4.53	5.10	5.69
	Stereo System	0.32	0.48	0.50	0.55	0.58	0.61	0.63	0.66	0.68	0.69	0.71
	Micro-wave	0.78	0.96	1.01	1.06	1.11	1.14	1.17	1.19	1.21	1.23	1.25
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.46	0.54	0.54	0.55	0.57	0.58	0.59	0.60	0.61	0.61	0.62
Anhui	Washing Machine	0.87	0.97	1.01	1.07	1.14	1.21	1.28	1.36	1.44	1.53	1.63
	Refrigerator	0.84	0.92	0.95	0.98	1.00	1.02	1.04	1.05	1.06	1.07	1.08

		2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Anhui	TV Set (color)	1.11	1.32	1.39	1.46	1.52	1.57	1.61	1.64	1.67	1.70	1.72
	Computer	0.07	0.26	0.53	0.85	1.20	1.60	2.03	2.49	2.98	3.51	4.06
	Stereo System	0.19	0.22	0.23	0.25	0.27	0.28	0.29	0.30	0.31	0.31	0.32
	Micro-wave	0.11	0.41	0.49	0.57	0.62	0.67	0.70	0.74	0.76	0.79	0.81
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.07	0.08	0.09	0.10	0.10	0.10	0.11	0.11	0.11	0.12	0.12
Henan	Washing Machine	0.88	0.98	1.02	1.04	1.06	1.07	1.08	1.09	1.09	1.10	1.10
	Refrigerator	0.72	0.86	0.90	0.93	0.94	0.96	0.97	0.98	0.99	0.99	1.00
	TV Set (color)	1.08	1.25	1.31	1.34	1.36	1.38	1.39	1.40	1.41	1.42	1.43
	Computer	0.06	0.32	0.54	0.76	0.97	1.17	1.37	1.55	1.74	1.92	2.10
	Stereo System	0.13	0.18	0.19	0.20	0.21	0.22	0.23	0.23	0.24	0.24	0.25
	Micro-wave	0.06	0.30	0.38	0.44	0.47	0.50	0.53	0.55	0.57	0.58	0.60
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.03	0.06	0.06	0.07	0.07	0.08	0.08	0.08	0.08	0.09	0.09
Jiangsu	Washing Machine	0.96	0.99	1.01	1.02	1.02	1.03	1.03	1.03	1.04	1.04	1.04
	Refrigerator	0.86	0.92	0.97	0.99	1.00	1.01	1.02	1.02	1.03	1.04	1.04
	TV Set (color)	1.24	1.53	1.66	1.74	1.79	1.83	1.86	1.89	1.91	1.94	1.95
	Computer	0.11	0.46	0.79	1.11	1.40	1.69	1.97	2.24	2.50	2.76	3.01
	Stereo System	0.20	0.28	0.29	0.31	0.33	0.34	0.34	0.35	0.36	0.36	0.37
	Micro-wave	0.37	0.77	0.89	0.97	1.03	1.08	1.12	1.15	1.18	1.20	1.22
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.15	0.18	0.16	0.17	0.17	0.17	0.18	0.18	0.18	0.18	0.18
Chong-qing	Washing Machine	0.95	1.00	1.03	1.04	1.05	1.06	1.07	1.07	1.08	1.09	1.09
	Refrigerator	1.00	1.02	1.07	1.10	1.11	1.12	1.13	1.14	1.15	1.15	1.16
	TV Set (color)	1.32	1.55	1.58	1.64	1.68	1.72	1.75	1.78	1.80	1.83	1.84
	Computer	0.14	0.51	0.78	1.15	1.54	1.96	2.40	2.85	3.32	3.80	4.30
	Stereo System	0.34	0.42	0.42	0.44	0.46	0.48	0.50	0.51	0.52	0.53	0.54
	Micro-wave	0.36	0.71	0.77	0.86	0.92	0.98	1.02	1.06	1.10	1.13	1.15
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.07	0.10	0.16	0.17	0.19	0.19	0.20	0.21	0.21	0.22	0.22
Hunan	Washing Machine	0.92	0.97	0.99	1.00	1.01	1.02	1.02	1.03	1.03	1.04	1.04
	Refrigerator	0.83	0.90	0.92	0.93	0.94	0.95	0.96	0.97	0.97	0.98	0.98
	TV Set (color)	1.09	1.29	1.31	1.35	1.39	1.43	1.45	1.48	1.50	1.52	1.53
	Computer	0.11	0.35	0.56	0.82	1.10	1.39	1.70	2.02	2.35	2.69	3.04
	Stereo System	0.28	0.33	0.33	0.36	0.38	0.40	0.41	0.42	0.43	0.44	0.45

		2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Hunan	Micro-wave	0.15	0.37	0.41	0.47	0.51	0.54	0.57	0.60	0.62	0.64	0.65
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.04	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06
Zhejiang	Washing Machine	0.90	0.91	0.94	0.95	0.95	0.96	0.96	0.97	0.97	0.98	0.98
	Refrigerator	0.96	0.98	0.99	1.00	1.00	1.00	1.00	1.01	1.01	1.01	1.01
	TV Set (color)	1.39	1.79	1.82	1.93	2.01	2.07	2.13	2.18	2.22	2.26	2.29
	Computer	0.14	0.59	0.97	1.49	2.08	2.73	3.42	4.16	4.94	5.76	6.61
	Stereo System	0.23	0.37	0.36	0.39	0.42	0.44	0.46	0.47	0.48	0.50	0.51
	Micro-wave	0.23	0.58	0.67	0.76	0.82	0.87	0.92	0.96	0.99	1.02	1.04
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.15	0.18	0.19	0.19	0.20	0.20	0.21	0.21	0.21	0.21	0.21
Hubei	Washing Machine	0.93	0.96	0.97	0.98	0.99	0.99	1.00	1.00	1.01	1.01	1.01
	Refrigerator	0.88	0.96	0.98	1.00	1.02	1.04	1.05	1.06	1.07	1.08	1.08
	TV Set (color)	1.09	1.32	1.36	1.42	1.47	1.50	1.54	1.56	1.59	1.61	1.63
	Computer	0.08	0.42	0.73	1.20	1.75	2.38	3.08	3.84	4.67	5.56	6.51
	Stereo System	0.25	0.32	0.34	0.37	0.39	0.40	0.42	0.43	0.44	0.45	0.46
	Micro-wave	0.10	0.47	0.53	0.61	0.67	0.72	0.76	0.79	0.82	0.85	0.87
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.05	0.07	0.07	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09
Jiangxi	Washing Machine	0.80	0.95	0.95	0.97	0.99	1.00	1.01	1.02	1.03	1.04	1.05
	Refrigerator	0.76	0.91	0.94	0.97	1.00	1.02	1.04	1.06	1.08	1.09	1.10
	TV Set (color)	1.06	1.39	1.45	1.54	1.60	1.66	1.70	1.74	1.78	1.81	1.84
	Computer	0.05	0.32	0.51	0.81	1.17	1.57	2.02	2.50	3.02	3.57	4.15
	Stereo System	0.16	0.25	0.27	0.30	0.31	0.33	0.34	0.35	0.36	0.37	0.38
	Micro-wave	0.07	0.39	0.46	0.53	0.59	0.63	0.67	0.70	0.72	0.75	0.77
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.02	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Yunnan	Washing Machine	0.92	0.90	0.98	0.99	0.99	1.00	1.00	1.00	1.00	1.01	1.01
	Refrigerator	0.70	0.78	0.81	0.84	0.86	0.88	0.89	0.91	0.92	0.93	0.94
	TV Set (color)	1.16	1.22	1.27	1.31	1.35	1.37	1.39	1.41	1.43	1.44	1.46
	Computer	0.08	0.29	0.49	0.75	1.03	1.33	1.65	1.99	2.34	2.71	3.09
	Stereo System	0.32	0.37	0.40	0.43	0.46	0.48	0.50	0.51	0.52	0.54	0.55
	Micro-wave	0.17	0.45	0.48	0.54	0.59	0.63	0.67	0.69	0.72	0.74	0.76
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.08	0.09	0.10	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.13

		2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Guizhou	Washing Machine	0.96	0.97	1.00	1.01	1.01	1.02	1.02	1.03	1.03	1.03	1.03
	Refrigerator	0.83	0.86	0.92	0.95	0.97	0.99	1.00	1.02	1.03	1.04	1.05
	TV Set (color)	1.14	1.25	1.28	1.32	1.36	1.38	1.41	1.43	1.45	1.46	1.48
	Computer	0.06	0.24	0.50	0.81	1.19	1.61	2.07	2.58	3.13	3.72	4.35
	Stereo System	0.31	0.39	0.42	0.46	0.49	0.51	0.53	0.55	0.57	0.58	0.59
	Micro-wave	0.13	0.35	0.43	0.49	0.53	0.57	0.60	0.63	0.65	0.67	0.69
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.04	0.05	0.06	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08
Guangxi	Washing Machine	0.88	0.92	0.97	1.01	1.03	1.05	1.06	1.07	1.08	1.09	1.09
	Refrigerator	0.80	0.87	0.93	0.96	0.98	1.00	1.02	1.04	1.05	1.06	1.07
	TV Set (color)	1.15	1.40	1.42	1.49	1.55	1.59	1.63	1.66	1.69	1.72	1.74
	Computer	0.09	0.47	0.78	1.26	1.83	2.47	3.17	3.94	4.78	5.67	6.61
	Stereo System	0.29	0.37	0.40	0.43	0.45	0.47	0.49	0.50	0.52	0.53	0.54
	Micro-wave	0.15	0.51	0.57	0.66	0.72	0.77	0.81	0.85	0.88	0.91	0.93
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.03	0.07	0.07	0.08	0.08	0.09	0.10	0.11	0.11	0.12	0.12
Guang-	Washing Machine	0.98	0.97	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
dong	Refrigerator	0.82	0.94	0.97	0.99	1.00	1.01	1.02	1.03	1.04	1.04	1.05
	TV Set (color)	1.36	1.55	1.62	1.68	1.73	1.77	1.81	1.84	1.87	1.89	1.91
	Computer	0.26	0.70	0.94	1.12	1.27	1.40	1.51	1.62	1.72	1.81	1.89
	Stereo System	0.49	0.57	0.59	0.62	0.64	0.66	0.68	0.69	0.71	0.72	0.73
	Micro-wave	0.30	0.61	0.73	0.80	0.86	0.90	0.94	0.97	1.00	1.03	1.05
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.07	0.13	0.14	0.16	0.18	0.20	0.22	0.24	0.26	0.27	0.29
Fujian	Washing Machine	0.93	1.00	1.00	1.02	1.03	1.04	1.04	1.05	1.06	1.06	1.07
	Refrigerator	0.88	0.98	1.03	1.07	1.10	1.12	1.14	1.16	1.17	1.19	1.20
	TV Set (color)	1.28	1.64	1.70	1.80	1.87	1.94	1.99	2.03	2.07	2.11	2.14
	Computer	0.11	0.55	0.74	0.84	0.92	0.98	1.04	1.09	1.13	1.17	1.20
	Stereo System	0.25	0.29	0.33	0.35	0.37	0.38	0.39	0.40	0.41	0.42	0.43
	Micro-wave	0.28	0.70	0.80	0.90	0.98	1.05	1.10	1.15	1.19	1.23	1.26
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.03	0.06	0.06	0.08	0.08	0.09	0.10	0.11	0.12	0.12	0.13
Hainan	Washing Machine	0.69	0.56	0.79	0.80	0.81	0.82	0.82	0.83	0.83	0.84	0.84
	Refrigerator	0.50	0.67	0.77	0.82	0.85	0.88	0.91	0.93	0.95	0.97	0.98
	TV Set (color)	1.09	1.17	1.24	1.28	1.31	1.33	1.35	1.37	1.39	1.40	1.41

		2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Hainan	Computer	0.04	0.26	0.49	0.80	1.17	1.59	2.05	2.55	3.10	3.69	4.31
	Stereo System	0.18	0.24	0.26	0.28	0.29	0.30	0.31	0.32	0.32	0.33	0.34
	Micro-wave	0.07	0.21	0.38	0.54	0.72	0.91	1.10	1.29	1.50	1.71	1.92
	Stove	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vacuum Cleaner	0.02	0.02	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04

Appendix 5. Energy share of DHW and cooking equipment

	DHW				COOKING		
	Electricity	Coal Gas	Nature Gas	LPG	Coal Gas	Nature Gas	LPG
Heilongjiang	0.20	0.06	0.36	0.38	0.07	0.45	0.47
Inner Mongolia	0.20	0.08	0.24	0.48	0.11	0.30	0.60
Qinghai	0.20	0.00	0.65	0.15	0.00	0.81	0.19
Tibet	0.20	0.00	0.00	0.80	0.00	0.00	1.00
Xinjiang	0.20	0.01	0.56	0.23	0.01	0.70	0.29
Jilin	0.20	0.15	0.20	0.45	0.19	0.25	0.56
Liaoning	0.40	0.16	0.23	0.21	0.27	0.38	0.35
Beijing	0.20	0.00	0.61	0.19	0.00	0.77	0.23
Tianjin	0.20	0.00	0.75	0.05	0.00	0.94	0.06
Hebei	0.20	0.10	0.36	0.34	0.13	0.45	0.42
Shandong	0.20	0.05	0.37	0.38	0.06	0.47	0.47
Ningxia	0.20	0.05	0.36	0.39	0.07	0.45	0.49
Sichuan	0.20	0.03	0.69	0.09	0.03	0.86	0.11
Shaanxi	0.20	0.00	0.55	0.25	0.00	0.69	0.31
Shanxi	0.20	0.27	0.34	0.19	0.34	0.43	0.23
Gansu	0.20	0.04	0.37	0.38	0.06	0.46	0.48
Shanghai	0.20	0.15	0.35	0.30	0.18	0.44	0.37
Anhui	0.20	0.01	0.40	0.39	0.01	0.50	0.49
Henan	0.20	0.10	0.39	0.31	0.13	0.49	0.38
Jiangsu	0.10	0.05	0.38	0.47	0.06	0.43	0.52
Chongqing	0.20	0.00	0.69	0.11	0.00	0.87	0.13
Hunan	0.10	0.03	0.29	0.57	0.04	0.33	0.64
Zhejiang	0.20	0.01	0.21	0.57	0.02	0.27	0.72
Hubei	0.20	0.03	0.32	0.46	0.03	0.40	0.57
Jiangxi	0.20	0.16	0.13	0.51	0.20	0.16	0.64
Yunnan	0.20	0.37	0.05	0.38	0.46	0.06	0.48
Guizhou	0.20	0.35	0.02	0.42	0.44	0.03	0.53
Guangxi	0.20	0.05	0.10	0.66	0.06	0.12	0.82
Guangdong	0.20	0.00	0.16	0.63	0.01	0.20	0.79
Fujian	0.20	0.01	0.18	0.61	0.01	0.23	0.76
Hainan	0.20	0.00	0.29	0.51	0.00	0.36	0.64

Appendix 6. Model estimates and statistics of electricity consumption (billion kWh)

	2000		2005	
	Model Estimates	Statistics	Model Estimates	Statistics
Heilongjiang	6.34	6.72	6.45	6.10
Inner Mongolia	0.50	0.51	2.58	2.64
Qinghai	0.44	0.44	0.75	0.74
Xinjiang	1.32	1.32	2.08	2.02
Jilin	2.89	2.93	3.79	3.62
Liaoning	3.60	3.67	7.75	8.23
Beijing	3.66	3.85	7.33	7.06
Tianjin	1.80	1.89	3.05	2.87
Hebei	4.94	5.02	7.84	7.25
Shandong	5.98	5.82	10.20	9.83
Ningxia	-	-	0.71	0.70
Sichuan	5.82	6.04	8.21	8.50
Shaanxi	2.18	2.13	3.98	3.68
Shanxi	1.63	1.70	2.91	2.81
Gansu	1.54	1.55	2.19	2.13
Shanghai	4.57	4.55	10.08	10.21
Anhui	3.41	3.15	5.27	4.80
Henan	4.71	4.75	6.63	6.27
Jiangsu	7.95	7.44	10.84	10.22
Chongqing	3.19	3.25	4.41	4.15
Hunan	3.12	3.22	6.54	6.52
Zhejiang	4.26	4.35	9.76	9.08
Hubei	4.47	4.50	8.43	7.74
Jiangxi	1.79	1.74	3.99	4.08
Yunnan	2.23	2.28	5.48	5.32
Guizhou	2.03	2.16	3.96	3.89
Guangxi	2.96	3.05	4.04	4.07
Guangdong	11.70	12.24	20.57	20.97
Fujian	3.63	3.77	7.16	7.02
Hainan	0.36	0.38	0.73	0.69

(Ningxia's electricity consumption was not included in the yearbook 2000)

Appendix 7. Projected CO_2 emissions by end use (million tons)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Beijing											
Heating	3.01	7.84	11.90	14.07	16.12	19.84	22.99	25.36	26.85	27.41	26.95
Cooling	0.10	0.36	0.46	0.48	0.45	0.49	0.50	0.49	0.47	0.38	0.31
DHW	1.42	1.85	2.07	1.81	1.67	1.85	2.00	1.91	1.80	1.66	1.51
Appliances	4.32	7.73	8.85	9.48	8.90	9.33	9.55	9.55	9.36	8.99	8.45
AS Reduction	0.00	0.00	0.00	2.22	5.04	5.09	6.80	8.57	10.40	12.12	13.71
RS Reduction	0.00	0.00	0.00	1.52	3.31	7.21	10.27	13.69	17.53	21.65	25.82
Total	**8.85**	**17.77**	**23.27**	**29.58**	**35.50**	**43.82**	**52.11**	**59.58**	**66.40**	**72.23**	**76.75**
Shanghai											
Heating	0.50	2.14	4.60	6.31	7.07	8.60	9.73	10.40	10.59	10.33	9.63
Cooling	0.49	1.57	2.25	2.61	2.67	3.09	3.40	3.59	3.65	3.26	2.83
DHW	1.25	1.52	1.73	1.60	1.51	1.70	1.83	1.91	1.93	1.74	1.53
Appliances	4.40	7.02	8.40	9.42	9.76	11.26	11.61	11.67	11.48	11.06	10.40
AS Reduction	0.00	0.00	0.00	4.09	10.89	11.40	15.44	19.79	24.27	28.02	31.24
RS Reduction	0.00	0.00	0.00	1.18	2.87	9.33	12.64	16.38	20.47	24.50	28.51
Total	**6.64**	**12.25**	**16.98**	**25.19**	**34.77**	**45.37**	**54.64**	**63.74**	**72.39**	**78.90**	**84.14**
Guangdong											
Heating	1.26	2.74	6.36	7.92	8.41	9.90	11.03	11.81	12.24	12.31	11.98
Cooling	2.27	4.95	8.61	9.41	9.24	10.30	10.98	11.31	11.32	11.01	9.42
DHW	3.29	4.07	6.52	6.09	5.89	6.79	7.57	8.23	8.76	8.30	7.75
Appliances	11.22	17.56	25.64	27.55	27.91	30.64	32.69	32.15	31.26	30.02	28.35
AS Reduction	0.00	0.00	0.00	9.23	23.07	23.65	32.49	40.81	49.60	58.00	63.91
RS Reduction	0.00	0.00	0.00	2.65	5.57	16.68	21.20	25.05	28.95	32.08	34.44
Total	**18.05**	**29.32**	**47.13**	**62.85**	**80.08**	**97.97**	**115.96**	**129.35**	**142.13**	**151.72**	**155.86**

Appendix 8. Projected CO_2 emissions by energy source (million tons)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Beijing											
Electricity	3.78	7.26	8.45	8.66	7.67	8.02	8.15	7.99	7.64	7.10	6.44
Coal Gas	0.24	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nature Gas	0.92	1.82	2.16	2.30	2.47	2.69	2.87	2.92	2.93	2.90	2.82
LPG	0.90	0.81	0.76	0.81	0.86	0.94	1.00	1.02	1.02	1.01	0.99
Coal	3.01	7.84	11.90	14.07	16.12	19.84	22.99	25.36	26.85	27.41	26.95
AS Reduction	0.00	0.00	0.00	2.23	5.05	5.11	6.82	8.59	10.42	12.15	13.73
RS Reduction	0.00	0.00	0.00	1.52	3.31	7.21	10.27	13.69	17.53	21.65	25.82
Total	**8.85**	**17.77**	**23.27**	**29.58**	**35.50**	**43.82**	**52.11**	**59.58**	**66.40**	**72.23**	**76.75**
Shanghai											
Electricity	4.73	10.04	14.69	17.44	18.32	21.70	23.41	24.26	24.26	23.07	21.20
Coal Gas	0.83	0.70	0.37	0.40	0.44	0.48	0.51	0.53	0.55	0.54	0.52
Nature Gas	0.13	0.59	0.98	1.05	1.14	1.24	1.33	1.39	1.43	1.40	1.35
LPG	0.95	0.93	0.95	1.02	1.10	1.21	1.29	1.35	1.39	1.36	1.31
Coal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AS Reduction	0.00	0.00	0.00	4.10	10.90	11.42	15.46	19.82	24.30	28.05	31.26
RS Reduction	0.00	0.00	0.00	1.18	2.87	9.33	12.64	16.38	20.47	24.50	28.51
Total	**6.64**	**12.25**	**16.98**	**25.19**	**34.77**	**45.37**	**54.64**	**63.74**	**72.39**	**78.90**	**84.14**
Guangdong											
Electricity	11.49	20.48	35.21	37.98	37.31	42.12	45.58	45.79	45.00	42.93	38.93
Coal Gas	0.49	0.34	0.06	0.07	0.07	0.08	0.08	0.09	0.09	0.09	0.09
Nature Gas	0.01	0.18	2.17	2.36	2.57	2.81	3.03	3.21	3.37	3.39	3.37
LPG	6.04	8.33	9.69	10.54	11.45	12.56	13.51	14.33	15.03	15.14	15.03
Coal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AS Reduction	0.00	0.00	0.00	9.26	23.12	23.71	32.55	40.88	49.68	58.08	64.00
RS Reduction	0.00	0.00	0.00	2.65	5.57	16.68	21.20	25.05	28.95	32.08	34.44
Total	**18.05**	**29.32**	**47.13**	**62.85**	**80.08**	**97.97**	**115.96**	**129.35**	**142.13**	**151.72**	**155.86**

Appendix 9. Regional projection of CO_2 emissions by end use (million tons)

	Heating	Cooling	DHW	Appliances	AS Reduction	RS Reduction
Heilongjiang	126.38	0.00	2.92	7.04	16.17	134.51
Inner Mongolia	59.97	0.00	1.68	4.39	11.38	72.06
Qinghai	12.16	0.00	0.40	1.46	2.28	14.75
Tibet	16.94	0.00	0.41	1.11	2.58	22.19
Xinjiang	80.59	0.00	1.89	7.30	14.12	95.84
Jilin	72.12	0.00	2.08	8.48	14.69	73.43
Liaoning	135.19	0.00	3.13	13.89	26.41	149.60
Beijing	26.95	0.31	1.51	8.45	13.71	25.82
Tianjin	14.96	0.31	1.83	4.98	9.06	15.60
Hebei	80.51	0.00	5.92	13.47	25.59	65.55
Shandong	61.48	3.44	5.76	17.05	38.22	74.29
Ningxia	6.32	0.00	0.63	1.54	2.54	5.43
Sichuan	55.95	0.00	4.80	16.34	23.38	50.11
Shaanxi	21.13	0.46	2.36	11.25	17.54	24.34
Shanxi	90.27	0.00	2.64	7.97	19.68	72.94
Gansu	20.24	0.00	1.51	5.09	6.70	17.60
Shanghai	9.63	2.83	1.53	10.40	31.24	28.51
Anhui	4.67	1.74	3.07	14.02	25.75	17.81
Henan	8.68	1.68	6.14	14.50	31.58	27.66
Jiangsu	21.40	5.41	6.63	19.42	63.15	61.22
Chongqing	5.72	2.21	1.53	8.19	21.28	19.45
Hunan	12.57	4.68	5.00	11.85	40.68	40.05
Zhejiang	16.25	4.98	4.22	20.13	57.16	49.95
Hubei	10.28	3.83	3.67	16.69	41.88	33.53
Jiangxi	3.65	1.69	3.42	9.14	19.45	14.91
Yunnan	4.37	0.00	2.73	8.52	14.31	8.84
Guizhou	3.74	0.00	2.36	7.45	12.79	7.58
Guangxi	3.35	2.58	3.54	14.55	27.53	12.73
Guangdong	11.98	9.42	7.75	28.35	63.91	34.44
Fujian	6.70	4.04	2.53	8.06	25.85	14.87
Hainan	0.68	0.68	0.66	2.14	5.30	2.58

Appendix 10. Estimated MAC of 31 districts

	POLICY	COST USD per ton	ABATEMENT Million tons
Heilongjiang	Thermal retrofit	-65.60	125.30
	Economy usage of air-conditioning	-85.21	7.18
	Economy usage of domestic hot water	-528.20	1.38
	Solar water heating	85.34	2.40
	Solar photovoltaic	2279.18	0.08
	High efficiency lighting	16.91	5.01
	Eco-appliances	1183.31	1.33
	Standby power savings	-505.25	1.18
	Average MAC / Total abatement	**-56.43**	**143.86**
Inner Mongolia	Thermal retrofit	-26.63	66.44
	Economy usage of air-conditioning	-49.15	3.81
	Economy usage of domestic hot water	-400.60	0.87
	Solar water heating	91.15	1.42
	Solar photovoltaic	2356.31	0.05
	High efficiency lighting	20.10	2.66
	Eco-appliances	1248.56	0.93
	Standby power savings	-419.25	1.34
	Average MAC / Total abatement	**-18.30**	**77.51**
Qinghai	Thermal retrofit	-29.25	13.57
	Economy usage of air-conditioning	-49.14	0.78
	Economy usage of domestic hot water	-354.38	0.21
	Solar water heating	74.79	0.34
	Solar photovoltaic	2018.29	0.01
	High efficiency lighting	19.17	0.54
	Eco-appliances	1234.24	0.18
	Standby power savings	-451.50	0.25
	Average MAC / Total abatement	**-21.97**	**15.87**
Tibet	Thermal retrofit	-39.73	20.74
	Economy usage of air-conditioning	-51.22	1.19
	Economy usage of domestic hot water	-367.88	0.21
	Solar water heating	59.62	0.34
	Solar photovoltaic	1409.28	0.01

	POLICY	COST USD per ton	ABATEMENT Million tons
Tibet	High efficiency lighting	10.20	0.83
	Eco-appliances	1308.64	0.15
	Standby power savings	-408.50	0.23
	Average MAC / Total abatement	**-34.38**	**23.70**
Xinjiang	Thermal retrofit	-34.27	88.80
	Economy usage of air-conditioning	-48.85	5.09
	Economy usage of domestic hot water	-409.39	0.98
	Solar water heating	74.92	1.60
	Solar photovoltaic	2216.20	0.05
	High efficiency lighting	13.94	3.55
	Eco-appliances	1210.75	0.77
	Standby power savings	-473.00	1.70
	Average MAC / Total abatement	**-32.16**	**102.53**
Jilin	Thermal retrofit	-33.89	66.77
	Economy usage of air-conditioning	-59.19	3.83
	Economy usage of domestic hot water	-533.71	1.00
	Solar water heating	80.99	1.72
	Solar photovoltaic	2224.07	0.05
	High efficiency lighting	21.55	2.67
	Eco-appliances	1186.64	1.03
	Standby power savings	-522.45	2.22
	Average MAC / Total abatement	**-33.44**	**79.29**
Liaoning	Thermal retrofit	-37.98	137.59
	Economy usage of air-conditioning	-59.89	7.88
	Economy usage of domestic hot water	-594.65	1.53
	Solar water heating	94.38	2.61
	Solar photovoltaic	2367.44	0.09
	High efficiency lighting	18.46	5.50
	Eco-appliances	1231.48	1.73
	Standby power savings	-483.75	3.84
	Average MAC / Total abatement	**-35.87**	**160.78**
Beijing	Thermal retrofit	-71.51	19.93
	Economy usage of air-conditioning	-208.70	4.05
	Economy usage of domestic hot water	-505.55	0.75

	POLICY	COST USD per ton	ABATEMENT Million tons
Beijing	Solar water heating	114.60	1.27
	Solar photovoltaic	2302.56	0.05
	High efficiency lighting	24.87	2.42
	Eco-appliances	1270.93	1.22
	Standby power savings	-473.00	1.75
	Average MAC / Total abatement	**-50.86**	**31.44**
Tianjin	Thermal retrofit	-33.95	11.22
	Economy usage of air-conditioning	-172.56	2.42
	Economy usage of domestic hot water	-515.52	0.89
	Solar water heating	61.58	1.53
	Solar photovoltaic	2436.42	0.03
	High efficiency lighting	28.48	1.36
	Eco-appliances	1269.49	0.72
	Standby power savings	-440.75	1.11
	Average MAC / Total abatement	**-32.38**	**19.28**
Hebei	Thermal retrofit	-52.43	51.03
	Economy usage of air-conditioning	-121.00	7.82
	Economy usage of domestic hot water	-572.65	2.42
	Solar water heating	67.74	4.72
	Solar photovoltaic	2248.79	0.12
	High efficiency lighting	21.30	6.18
	Eco-appliances	1175.41	2.22
	Standby power savings	-526.75	2.70
	Average MAC / Total abatement	**-40.20**	**77.21**
Shandong	Thermal retrofit	-328.58	57.00
	Economy usage of air-conditioning	-272.53	17.98
	Economy usage of domestic hot water	-548.56	2.42
	Solar water heating	88.41	4.61
	Solar photovoltaic	2297.44	0.15
	High efficiency lighting	22.94	7.34
	Eco-appliances	1119.09	2.72
	Standby power savings	-559.00	3.16
	Average MAC / Total abatement	**-238.68**	**95.37**
Ningxia	Thermal retrofit	-12.61	4.05

	POLICY	COST USD per ton	ABATEMENT Million tons
Ningxia	Economy usage of air-conditioning	-94.97	0.62
	Economy usage of domestic hot water	-393.00	0.26
	Solar water heating	61.69	0.50
	Solar photovoltaic	1853.75	0.01
	High efficiency lighting	26.15	0.49
	Eco-appliances	1218.31	0.20
	Standby power savings	-480.52	0.33
	Average MAC / Total abatement	**-8.35**	**6.46**
Sichuan	Thermal retrofit	34.12	107.39
	Economy usage of air-conditioning	-500.63	16.46
	Economy usage of domestic hot water	-440.70	2.00
	Solar water heating	81.28	3.87
	Solar photovoltaic	3706.74	0.08
	High efficiency lighting	28.20	4.61
	Eco-appliances	1237.72	2.31
	Standby power savings	-500.63	2.87
	Average MAC / Total abatement	**-23.64**	**139.58**
Shaanxi	Thermal retrofit	-50.58	17.22
	Economy usage of air-conditioning	-208.74	3.70
	Economy usage of domestic hot water	-473.38	1.01
	Solar water heating	87.07	1.90
	Solar photovoltaic	2559.04	0.06
	High efficiency lighting	32.80	2.09
	Eco-appliances	1197.45	1.20
	Standby power savings	-526.75	3.04
	Average MAC / Total abatement	**-63.13**	**30.22**
Shanxi	Thermal retrofit	-90.99	61.25
	Economy usage of air-conditioning	-120.76	9.39
	Economy usage of domestic hot water	-559.66	1.10
	Solar water heating	75.76	2.13
	Solar photovoltaic	2235.35	0.06
	High efficiency lighting	8.95	7.42
	Eco-appliances	1171.97	1.11
	Standby power savings	-510.62	1.84

	POLICY	COST USD per ton	ABATEMENT Million tons
Shanxi	**Average MAC / Total abatement**	**-78.25**	**84.30**
Gansu	Thermal retrofit	-33.55	13.77
	Economy usage of air-conditioning	-105.83	2.11
	Economy usage of domestic hot water	-435.89	0.74
	Solar water heating	72.98	1.25
	Solar photovoltaic	2225.12	0.03
	High efficiency lighting	22.58	1.67
	Eco-appliances	1199.80	0.70
	Standby power savings	-505.25	0.61
	Average MAC / Total abatement	**-12.88**	**20.88**
Shanghai	Thermal retrofit	-529.02	15.54
	Economy usage of air-conditioning	-651.81	5.70
	Economy usage of domestic hot water	-608.43	0.66
	Solar water heating	134.87	1.24
	Solar photovoltaic	2316.02	0.06
	High efficiency lighting	14.20	4.88
	Eco-appliances	1152.31	1.53
	Standby power savings	-655.75	2.73
	Average MAC / Total abatement	**-370.88**	**32.33**
Anhui	Thermal retrofit	-201.92	7.46
	Economy usage of air-conditioning	-594.18	2.76
	Economy usage of domestic hot water	-580.38	1.32
	Solar water heating	110.14	2.47
	Solar photovoltaic	2374.21	0.09
	High efficiency lighting	48.08	2.34
	Eco-appliances	1144.41	2.14
	Standby power savings	-602.00	3.15
	Average MAC / Total abatement	**-126.59**	**21.74**
Henan	Thermal retrofit	-209.29	12.21
	Economy usage of air-conditioning	-540.01	4.52
	Economy usage of domestic hot water	-481.37	2.61
	Solar water heating	74.52	4.95
	Solar photovoltaic	2303.51	0.13
	High efficiency lighting	39.73	3.83

	POLICY	COST USD per ton	ABATEMENT Million tons
Henan	Eco-appliances	1175.29	2.53
	Standby power savings	-548.25	2.26
	Average MAC / Total abatement	**-111.78**	**33.03**
Jiangsu	Thermal retrofit	-404.30	32.12
	Economy usage of air-conditioning	-554.67	11.80
	Economy usage of domestic hot water	-580.36	2.84
	Solar water heating	80.71	5.33
	Solar photovoltaic	2516.54	0.14
	High efficiency lighting	17.59	10.08
	Eco-appliances	1223.00	3.55
	Standby power savings	-559.00	3.85
	Average MAC / Total abatement	**-258.41**	**69.71**
Chongqing	Thermal retrofit	-332.66	10.34
	Economy usage of air-conditioning	-494.96	3.79
	Economy usage of domestic hot water	-383.96	0.68
	Solar water heating	118.29	1.25
	Solar photovoltaic	3582.59	0.04
	High efficiency lighting	18.88	3.24
	Eco-appliances	1248.96	1.25
	Standby power savings	-497.72	1.84
	Average MAC / Total abatement	**-204.77**	**22.42**
Hunan	Thermal retrofit	-434.79	20.74
	Economy usage of air-conditioning	-584.68	7.62
	Economy usage of domestic hot water	-598.81	2.17
	Solar water heating	72.98	4.02
	Solar photovoltaic	2778.22	0.09
	High efficiency lighting	18.54	6.51
	Eco-appliances	1153.00	2.06
	Standby power savings	-589.10	2.56
	Average MAC / Total abatement	**-289.22**	**45.76**
Zhejiang	Thermal retrofit	-436.10	25.96
	Economy usage of air-conditioning	-566.39	9.52
	Economy usage of domestic hot water	-609.55	1.81
	Solar water heating	89.82	3.38

	POLICY	COST USD per ton	ABATEMENT Million tons
Zhejiang	Solar photovoltaic	2505.80	0.10
	High efficiency lighting	15.36	8.15
	Eco-appliances	1251.87	2.73
	Standby power savings	-569.75	5.65
	Average MAC / Total abatement	**-295.66**	**57.29**
Hubei	Thermal retrofit	-375.80	16.33
	Economy usage of air-conditioning	-558.12	5.99
	Economy usage of domestic hot water	-595.82	1.58
	Solar water heating	89.21	2.95
	Solar photovoltaic	2531.79	0.09
	High efficiency lighting	21.18	5.12
	Eco-appliances	1172.49	2.01
	Standby power savings	-562.22	4.78
	Average MAC / Total abatement	**-261.67**	**38.85**
Jiangxi	Thermal retrofit	-239.95	6.11
	Economy usage of air-conditioning	-595.27	2.25
	Economy usage of domestic hot water	-761.06	1.48
	Solar water heating	63.93	2.75
	Solar photovoltaic	2416.19	0.06
	High efficiency lighting	37.52	1.92
	Eco-appliances	1154.19	1.43
	Standby power savings	-602.00	2.06
	Average MAC / Total abatement	**-173.35**	**18.07**
Yunnan	Thermal retrofit	727.84	1.55
	Economy usage of air-conditioning	-418.40	0.96
	Economy usage of domestic hot water	-353.70	1.16
	Solar water heating	73.82	2.20
	Solar photovoltaic	2015.75	0.07
	High efficiency lighting	33.97	1.98
	Eco-appliances	1309.38	1.09
	Standby power savings	-432.15	1.46
	Average MAC / Total abatement	**142.22**	**10.46**
Guizhou	Thermal retrofit	600.46	1.27
	Economy usage of air-conditioning	-425.20	0.77

	POLICY	COST USD per ton	ABATEMENT Million tons
Guizhou	Economy usage of domestic hot water	-344.36	1.00
	Solar water heating	63.59	1.90
	Solar photovoltaic	3261.39	0.03
	High efficiency lighting	30.79	1.62
	Eco-appliances	1287.21	0.86
	Standby power savings	-433.22	1.49
	Average MAC / Total abatement	**93.13**	**8.96**
Guangxi	Thermal retrofit	905.21	1.58
	Economy usage of air-conditioning	-484.15	3.98
	Economy usage of domestic hot water	-893.98	1.50
	Solar water heating	73.10	2.82
	Solar photovoltaic	2636.21	0.07
	High efficiency lighting	33.59	2.51
	Eco-appliances	1263.83	1.61
	Standby power savings	-486.97	3.79
	Average MAC / Total abatement	**-66.37**	**17.86**
Guangdong	Thermal retrofit	570.00	5.77
	Economy usage of air-conditioning	-650.99	14.54
	Economy usage of domestic hot water	-810.58	3.30
	Solar water heating	102.66	6.18
	Solar photovoltaic	2744.47	0.19
	High efficiency lighting	28.51	9.17
	Eco-appliances	1119.65	5.19
	Standby power savings	-655.75	3.76
	Average MAC / Total abatement	**-84.97**	**48.09**
Fujian	Thermal retrofit	295.87	2.88
	Economy usage of air-conditioning	-450.87	7.24
	Economy usage of domestic hot water	-768.96	1.09
	Solar water heating	96.10	2.03
	Solar photovoltaic	2645.20	0.06
	High efficiency lighting	17.55	4.57
	Eco-appliances	1317.69	1.80
	Standby power savings	-453.65	0.81
	Average MAC / Total abatement	**-39.10**	**20.49**

	POLICY	COST USD per ton	ABATEMENT Million tons
Hainan	Thermal retrofit	709.61	0.36
	Economy usage of air-conditioning	-640.97	0.91
	Economy usage of domestic hot water	-591.22	0.29
	Solar water heating	87.01	0.53
	Solar photovoltaic	2755.37	0.01
	High efficiency lighting	32.92	0.58
	Eco-appliances	1079.24	0.31
	Standby power savings	-645.00	0.59
	Average MAC / Total abatement	**-121.85**	**3.58**

Appendix 11. Temperature and degree days

District	Weather Station	Average Temperature (°C)												Degree Day	
		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	CDD24	HDD18
Heilongjiang	Harbin	-18.30	-13.60	-3.40	7.10	14.70	20.40	23.00	21.10	14.50	5.60	-5.30	-14.80	0.00	5308.00
Inner Mongolia	Hohhot	-11.60	-7.20	0.30	9.00	16.10	20.70	22.60	20.60	14.60	7.00	-2.10	-9.40	0.00	4396.20
Qinghai	Xining	-7.40	-3.90	1.80	8.00	12.40	15.30	17.20	16.60	12.20	6.50	-0.20	-5.70	0.00	4336.80
Tibet	Lhasa	-1.60	1.50	5.20	8.40	12.30	15.90	15.70	14.70	12.90	8.70	2.90	-1.20	0.00	3657.20
Xinjiang	Urumqi	-12.60	-9.70	-1.70	9.90	16.70	21.50	23.70	22.40	16.70	7.70	-2.50	-9.30	0.00	4437.80
Jilin	Changchun	-15.10	-10.70	-2.00	7.80	15.20	20.60	23.10	21.60	15.40	7.00	-3.40	-11.70	0.00	4824.20
Liaoling	Shenyang	-11.00	-6.90	1.20	10.20	17.00	22.00	24.60	23.60	17.40	9.50	0.30	-7.50	18.60	3985.00
Beijing	Beijing	-3.70	-0.70	5.80	14.20	19.90	24.40	26.20	24.80	20.00	13.10	4.60	-1.50	105.00	2846.90
Tianjin	Tianjin	-3.50	-0.60	5.90	14.30	20.00	24.60	26.60	25.60	20.90	13.90	5.30	-1.10	148.20	2773.60
Hebei	Chengde	-9.10	-4.90	2.60	11.90	18.30	22.60	24.40	22.70	17.20	9.90	0.40	-6.90	12.40	3716.70
Shandong	Jinan	-0.40	2.20	8.20	16.10	21.80	26.30	27.50	26.30	22.00	16.10	8.30	1.80	248.80	2225.70
Ningxia	Yinchuan	-7.90	-3.80	3.20	11.20	17.30	21.50	23.40	21.60	16.20	9.20	1.40	-5.50	0.00	3651.10
Sichuan	Jiulong	1.10	3.40	6.70	9.50	12.70	14.60	15.10	14.70	13.00	9.90	4.90	1.30	0.00	3308.30
Shaanxi	Xi'an	-0.10	2.90	8.10	14.70	19.80	24.80	26.60	25.30	19.90	13.90	6.90	1.30	144.90	2367.60
Shanxi	Taiyuan	-5.50	-2.00	4.20	12.20	18.10	21.80	23.40	21.90	16.50	10.10	2.50	-3.70	0.00	3317.90
Gansu	Lanzhou	-5.30	-1.00	5.40	12.10	17.00	20.40	22.40	21.10	16.30	9.80	2.50	-3.90	0.00	3302.00
Shanghai	Shanghai	4.70	6.00	9.20	14.70	20.30	23.80	28.00	27.80	24.40	19.20	13.50	7.80	253.80	1571.30
Anhui	Anqing	4.00	5.80	9.90	16.50	21.80	25.30	28.70	28.40	23.70	18.30	12.00	6.40	321.10	1611.30
Henan	Zhengzhou	0.10	2.70	8.00	15.50	21.00	25.70	27.00	25.60	21.00	15.10	8.00	2.20	193.60	2248.00

District	Weather Station	Average Temperature (°C)												Degree Day	
		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	CDD24	CDD24
Jiangsu	Nanjing	2.40	4.20	8.70	15.20	20.50	24.40	27.80	27.40	22.80	17.10	10.40	4.50	235.20	1916.70
Chongqing	Shapingba	7.80	9.50	13.60	18.40	22.30	25.10	28.10	28.40	23.60	18.60	14.00	9.30	296.50	1080.30
Hunan	Changsha	4.90	7.10	10.30	17.00	22.00	25.40	28.60	28.10	23.60	18.10	12.40	7.70	311.70	1467.30
Zhejiang	Hangzhou	4.30	5.60	9.50	15.80	20.70	24.30	28.40	27.90	23.40	18.30	12.40	6.80	266.30	1616.60
Hubei	Wuhan	3.70	5.80	10.10	16.80	21.90	25.60	28.70	28.20	23.40	17.70	11.40	6.00	323.90	1645.10
Jiangxi	Nanchang	5.30	6.90	10.90	17.30	22.30	25.70	29.20	28.80	24.60	19.40	13.30	7.80	379.00	1402.80
Yunnan	Kunming	8.10	9.90	13.20	16.60	19.00	19.90	19.80	19.40	17.80	15.40	11.60	8.20	0.00	1306.90
Guizhou	Guiyang	5.10	6.60	11.00	16.10	19.60	22.20	23.90	23.60	20.60	16.30	11.80	7.40	0.00	1560.40
Guangxi	Nanning	12.80	14.10	17.60	22.50	25.90	27.90	28.40	28.20	26.90	23.50	18.90	14.90	529.50	378.90
Guangdong	Guangzhou	13.60	14.50	17.90	22.10	25.50	27.60	28.60	28.40	27.10	24.20	19.60	15.30	532.70	321.20
Fujian	Fuzhou	10.90	11.00	13.50	18.20	22.20	26.00	28.90	28.40	25.90	22.10	17.70	13.20	405.30	713.40
Hainan	Haikou	17.70	18.70	21.70	25.10	27.40	28.40	28.60	28.10	27.10	25.30	22.20	19.00	673.40	0.00

Appendix 12. Information of the subjected households (from section 5.3)

Subject	**City**	**Climate**	**Floor area (sqm)**	**Energy source**				**Household size (person)**
				Heating	**Cooling**	**DHW**	**Cooking**	
01	Shanghai	HSCW	129.6	Electricity	Electricity	City gas	City gas	4
02			130.0	Electricity	Electricity	Regional hot water supply	City gas	3
03	Changsha	HSCW	106.0	Electricity	Electricity	Electricity	City gas	4
04			103.0	Electricity	Electricity	City gas	City gas	3
05	Harbin	Severe cold	180.5	Central heating	-	Regional hot water supply	City gas	3
06			104.0	Central heating	-	Electricity	City gas	3
07	Beijing	Cold	80.5	City gas	Electricity	City gas	City gas	3
08			90.0	Central heating	Electricity	City gas	City gas	3
09	Dalian	Cold	101.4	Central heating	Electricity	Solar heat	City gas	2
10			89.0	Central heating	Electricity	Electricity	City gas	4
11	Shenyang	Cold	110.0	Central heating	-	Electricity	City gas	5
12			100.0	Central heating	-	Electricity	City gas	3

HSCW: Hot Summer Cold Winter area

Town And Country Air

It's both town and country air
that we ultimately share.
So polluting one expect
to get a butterfly effect.

If the key to all our health
is to share in nature's wealth
then we'd best invest a plan
to save our wildlife while we can.

(Celia Berrell)