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Bin Su
Elspeth Thomson *Editors*

China's Energy Efficiency and Conservation

Household Behaviour, Legislation, Regional Analysis and Impacts

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The Energy Studies Institute (ESI) at the National University of Singapore started its China energy research in 2012. Its first conference on "China Energy Issues in the 12th Five-Year Plan and Beyond", held in February 2012, examined the economic, environmental, and security aspects of China's energy and carbon mitigation strategies. During this event, speakers and participants shared their opinions on China's overall energy developments, and some of these discussions have been published in journals, such as in volume 73 of *Energy Policy* (Special Issue, 2014).

ESI has established formal relationships with energy think-tanks in China—such as the Institute of Policy and Management, the Chinese Academy of Sciences, and the College of Economics and Management in Nanjing University of Aeronautics and Astronautics—to look into China's latest energy issues and their influences on the region. In 2013, the Institute launched a series called the "Singapore–China Energy Forum" to discuss the opportunities and challenges faced by China's recent and future energy developments. The topics included energy efficiency and conservation, energy and carbon markets, energy security, climate change, and many others. This volume is the compilation of presentations on the subject of energy efficiency and conservation delivered at the first forum, held in November 2013.

On behalf of the ESI research team, I would like to express our sincerest thanks to our Executive Director, Prof. S.K. Chou, and ESI's board members for their unwavering support towards our China energy research and the Singapore–China Energy Forum series. We are also grateful to our administrative colleagues, including Mr. Peter Yap, Ms. Jan Lui, and Ms. S. Telagavathy, who assisted in the management of our events. Our special thanks also go to ESI's Publications Committee, especially our Editor Ms. Eunice Low, who spent much time reading and copyediting earlier drafts of our manuscripts. Last but not least, we would like to thank all the speakers, authors, reviewers, participants, and research partners.

With our continued efforts in China energy research, we hope to generate constant and fruitful discussions in this area.

Singapore
November 2015

Dr. Bin Su

Contents

Chapter 1
Introduction

Bin Su and Elspeth Thomson

As China is the world's largest energy consumer and carbon emitter, it is under a great deal of international pressure to try to minimise its consumption of fossil fuels and to employ all possible means to minimise the resulting carbon emissions. The progress that has been made in recent years to harness solar and wind power have been very impressive. So too have been the gains made in energy efficiency and energy conservation, especially considering the country's massive size and diversity. Parts of the country still focus primarily on heavy industries, while others specialise in light industries and/or services. Some sectors have been able to greatly improve their energy efficiency, while others have not made much headway at all.

China's energy efficiency and conservation was the theme of a conference held in Singapore in November 2013. This volume features half the presentations which were delivered at this *1st Singapore–China Energy Forum*, organised by the National University of Singapore's Energy Studies Institute. The speakers at this event, from mainland China, Hong Kong, Taiwan, Australia, Singapore and Japan, discussed the opportunities and challenges facing China's energy efficiency and conservation developments, including: (a) sectoral energy efficiency/conservation strategies and their impacts; (b) energy efficiency/conservation projects and regulation; and (c) relationships between energy efficiency/conservation and other socio-economic factors.

Volume I, *China's Energy Efficiency and Conservation: Sectoral Analysis*, examined energy efficiency and conservation in five specific sectors: power generation, energy-intensive manufacturing, iron and steel, transport and building. This present volume, *China's Energy Efficiency and Conservation: Household*

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Behaviour, Legislation, Regional Analysis and Impacts, examines the energy consumption behaviour of Chinese households; estimates potential energy savings and GHG emission reductions resulting from energy efficiency measures; calculates the total factor energy efficiency and pollution efficiency indices for the country's 29 provinces and regions; looks at China's basic energy conservation and energy efficiency legislation and policy frameworks; and compares China's approaches to energy efficiency with those of Japan.

Specifically, in Chap. 2, Chu Wei et al. discuss the energy consumption profile of Chinese households in 2012 using data from the CRECS-2012 survey dataset (1,450 households). Their survey results include the following major findings: (a) average energy consumption in Chinese households in 2012 was around 44 per cent of that in the US in 2009, and 38 per cent of that in the EU-27 in 2008; (b) space heating accounted for over half of total household energy consumption, and the barrier to energy efficiency improvement in space heating lay in the pricing system for district heating; and (c) although the Chinese government subsidises various energy efficiency appliances, the purchase rate for these highly efficient appliances is still low.

Philip Andrews-Speed and Guo Ma note how Chinese households are accounting for an increasing share of energy use in China. In Chap. 3, they combine the evidence revealed from the international literature on household energy behaviours, and a number of surveys carried out in China, with their studies in Chongqing city, to explore the nature of the policy challenges facing the Chinese government. Household behaviour, with respect to energy conservation, is found to be affected by knowledge, awareness, attitudes, preferences, and other socio-demographic factors. Andrews-Speed and Ma discuss the policy implications for the Chinese government in its bid to promote household energy savings.

Chapter 4 looks into the potential energy savings and GHG emissions reductions resulting from energy efficiency. Youguo Zhang first uses input–output structural decomposition analysis to study the total energy and carbon emission changes in the past, and then constructs a dynamic computable general equilibrium model to simulate the potential effects of energy efficiency improvements on energy savings and emission reductions from 2013 to 2030. Three scenarios (baseline, moderate and ambitious) are considered in the simulation. Compared with the baseline scenario, the moderate/ambitious scenarios lead to savings of 36.1/48.4 billion tonnes of coal equivalent energy and reductions in carbon emissions of 21.0/28.2 billion tonnes.

Economic development, and energy and carbon intensities vary considerably across China. In Chap. 5, Jin-Li Hu and Tzu-Pu Chang use data envelopment analysis to derive the ecological total-factor energy efficiency and pollution efficiency indices for China's 29 provinces and regions from 2001 to 2011. The results show that the ecological total-factor pollution efficiency is always lower than the ecological total-factor energy efficiency for any jurisdiction in the same year. In other words, China is facing a more serious situation in pollution control than energy saving. The authors recommend both input (e.g. energy saving) and output (e.g. air pollution) regulations at the national and regional levels.

Chapter 6 discusses China's basic legislation and policy frameworks with respect to energy conservation and energy efficiency. Haifeng Deng claims that although some progress has been made in improving China's regulation of energy conservation and energy efficiency, some obstacles and gaps can be identified in the legislation and policies. Some of these include the fact that the energy law system and administrative management system are not complete; the difficulty in integrating legislation on energy conservation and climate change due to basic underlying differences; and the many challenges in enforcing energy conservation and energy efficiency systems.

In the final chapter, Mikiko Kainuma and Osamu Akashi summarise Japan's energy efficiency and conservation strategies and discuss relevant lessons for China. Over many years, Japan has successfully resolved some of its environmental problems through energy efficiency improvements. The authors construct mitigation scenarios to halve global GHG emissions by 2050 and analyse various technologies needed in Japan and China to further reduce their GHG emissions.

The world is anxiously watching how China goes about tapering its energy consumption and capping its carbon emissions while maintaining its economic growth and modernisation. It is no easy task to formulate effective policies for such a huge geographical area and large population. Increasing numbers of Chinese citizens, especially in the coastal areas, are very concerned about the planet and fully understand China's role in mitigating climate change, but there are still great numbers of people in the more rural areas who are necessarily more concerned with their own survival.

It is extremely challenging for the central government to first come up with reasonable national targets, and then work with the provincial/regional and municipal governments to achieve them. A major requirement for achieving them is the formulation and enforcement of laws relating to energy consumption in industries, businesses, homes and transport. But before effective laws can be made, it is first necessary to gather and analyse data pertaining to energy use around the entire country. The amounts of data that Chinese governments and scholars have been collecting in recent years are phenomenal, and with each passing year, more and more clarity is being reached over the extent of energy wastage in each sector. With such information, governments and scholars around the world are proposing many different ways to minimise this wastage and concomitantly, the carbon emissions.

Volumes I and II of *China's Energy Efficiency and Conservation* are examples of international, collaborative efforts to help China find ways to provide its vast population with adequate energy to ensure continuously improving lifestyles, but at the same time reduce energy intensities as quickly as possible and cause the least harm to the planet.

Chapter 2
A Survey Analysis of Energy Use and Conservation Opportunities in Chinese Households

Chu Wei, Ping Qing, Feng Song, Xinye Zheng, Yihua Yu, Jin Guo and Zhanming Chen

Abstract Based on the detailed CRECS-2012 dataset with 1,450 surveyed households, this study provides a brief overview of Chinese energy consumption at the household level in 2012. Furthermore, this study investigates the various types of household energy conservation behaviour. We have several major findings. First, our results show that a representative Chinese household in 2012 consumed 1,426 kgce (standard coal equivalent), which is approximately 44 % of that in the US in 2009, and 38 % of that in the EU 27 in 2008. Space heating is the most energy-intensive activity in a household, accounting for over half of the consumption. Second, the barrier to energy efficiency in space heating lies in the current pricing system of district heating. In order to improve the individual incentive to conserve energy, the reform should be carried out so that heating charges are made according to the actual usage. Third, although there are various government programmes to subsidise energy-efficient appliances, the purchase rate for less energy-intensive appliances, such as TVs, water heaters and computers, is still low. This calls for more research to understand the determinants of household energy conservation behaviour.

Keywords Household survey · Energy consumption · China

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2.1 Introduction

China's huge energy demand and its related CO_2 emissions have attracted a lot of attention both internationally and domestically. In 2010, China overtook the United States and became the largest consumer of energy products in the world (EIA 2014). The energy demand of the residential sector, as shown in Fig. 2.1, is continuously increasing and is the second largest user among all sectors. In 2011, the residential sector (excluding private transportation) consumed 374.1 Mtce, accounting for 11 % of national total consumption (NBS 2012).

There are two reasons behind the prediction that China's residential energy demand will continue to grow rapidly in the near future. First, there is still a vast gap in energy consumption per capita between China and other developed countries. As shown in Fig. 2.2, China's per capita household electricity usage is far

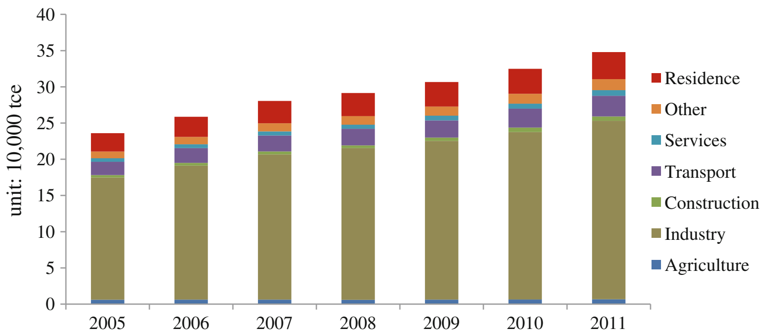

Fig. 2.1 Total energy consumption by sector in China (2005–11, unit: 10,000 tce). *Source* NBS, *China Statistical Yearbook*, various years

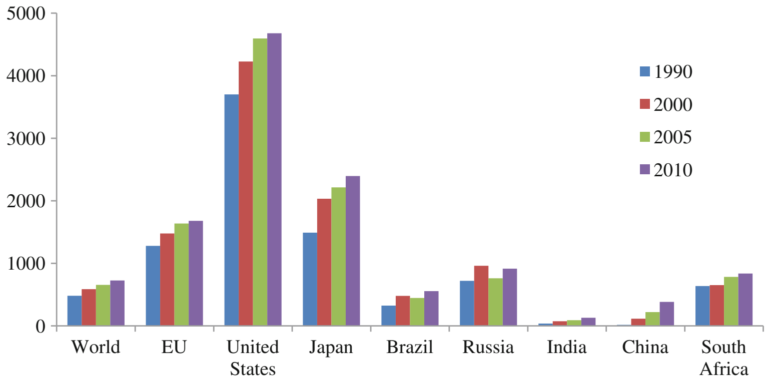

Fig. 2.2 Average electricity consumption of households per capita (unit: kWh/person). *Source* World Energy Council (2014)

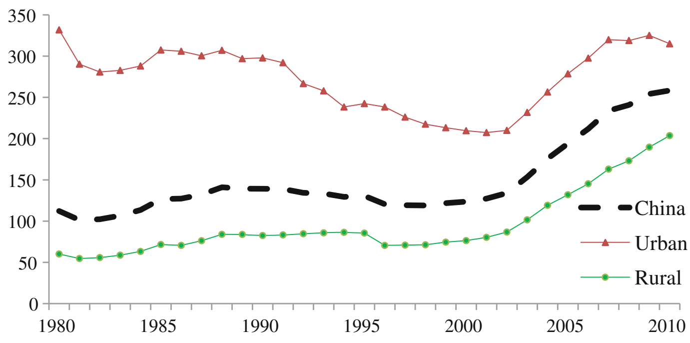

Fig. 2.3 Per capita household energy consumption in urban and rural area (1980–2010, unit: kgce). *Source* NBS (2012)

lower than that of developed countries, most transition countries and the world average. China is now on the industrialisation track. The catch-up process, accompanied by the people's need to improve their living standards, will inevitably generate rapid energy demand.

Another reason for the surging energy demand is the giant urban-rural gap within the country and the accelerating urbanisation process. In the 1980s, per capita energy consumption in the urban areas was five times that in the rural areas (see Fig. 2.3). Although this ratio is narrowing, the city-dweller still consumed 50 % more than in the rural resident in 2010.[1] Meanwhile, around 100 million rural residents are expected to urbanise by 2020, raising the urbanisation rate from 52.6 % in 2013 to 60 % (China daily 2013). This vast population migration and resettlement will lead to not only an increase in energy demand but also the energy transition from biomass to modern commercial energy.

On one hand, this strong energy demand reflects the improvement in people's quality of life and economic development level (Niu et al. 2012). On the other hand, it places increasingly tight constraints on resources and the environment. More importantly, it may conflict with, rather than contribute to, China's efforts towards energy conservation and GHG abatement. Among all energy conservation and climate change mitigation options, the improvement in energy efficiency played a vital role and was the most effective way to manage and restrain the growth in energy consumption, and reduce emissions globally (Ürge-Vorsatz/Metz 2009). It is important for both decision-makers and the public to understand the actual situation and characteristics of household energy efficiency, and then identify the underlying opportunities, policy measures, as well as challenges to conserve energy in China's residential sector. However, existing studies on household energy

[1]The narrowing urban-rural gap is due to the wide use of commercial energy (i.e. natural gas in the cities) and a broader statistical coverage (i.e. biomass usage in rural areas).

consumption are not sufficiently in-depth. One reason is that more attention has been paid to the industrial sector—the largest energy user. Another reason is the lack of household-level data.

To fill his gap, Renmin University conducted the first Chinese Residential Energy Consumption Survey (CRECS) from December 2012 to March 2013, during which 1,450 surveyed households were surveyed. Based on the detailed data from the CRECS, this study provides a brief overview of Chinese energy consumption at the household level in 2012, and allows us to have a better understanding of household energy conservation behaviour.

The remainder of this chapter is organised as follows. Section 2.2 reviews the energy conservation policies in the residential sector. Section 2.3 introduces the survey and presents the estimation of household energy consumption. Section 2.4 discusses the energy conservation opportunities and challenges. The conclusions and policy implications are given in the final section.

2.2 Energy Conservation Policies in the Residential Sector

The Chinese government has carried out a series of projects to promote energy efficiency and curb excessive energy consumption, including various policies introduced in the residential sector. In order to improve both consumer awareness about energy efficiency and minimise the use of less efficient appliances, in August 2004 the Chinese government began an energy efficiency labelling and product identification programme. This labelling management system, also known as the China Energy Label, is a type of information tag attached to the product, which indicates the energy efficiency grade, energy consumption and other indices of energy-using products. Labelling is done on a scale of one to five, with one being the most efficient and five the least. The programme initially covered only three appliances: air-conditioners, refrigerators, and washing machines. However, the mandatory energy efficiency labelling programme presently includes personal computer monitors, light LCD TVs, plasma TVs, electric rice cookers, induction cookers, washing machines, refrigerators, electric heaters, printers, copy machines, compact fluorescent lamps, high pressure sodium lamps, and electric fans.

To further improve energy efficiency in the residential sector, in 2009 the government launched a project to promote 10 different types of energy-efficient products through the issuance of financial subsidies for products such as high-efficiency illumination products and energy-efficient motors. Energy-efficient products refer to those with energy efficiency labels of 1 and 2. To promote the use of these products and benefits to the consumer, financial subsidies are provided at various levels based on the types of products as well as labels. For example, a customer who purchases an air conditioner unit with an energy efficiency label of 2 will enjoy a subsidy of RMB 300–650, while products labelled with an energy efficiency label of 1 will come with a subsidy of RMB 500–850. In that year, in order to reduce vehicle-related fuel use and air pollution, the government also initiated a project called “replace old automobiles with new ones”. According to this regulation, owners who retired their old or yellow-label[2] vehicles early were entitled to government subsidies at various levels from RMB 3,000–6,000.

To change consumers’ behaviour and make them more responsive to resource and energy prices, the government has made comprehensive plans to carry out pricing reforms for electricity, water, oil, and natural gas. The first pricing reform was conducted in the electricity sector. Pilot experiments of electricity pricing reform were carried out in three provinces, namely Sichuan, Fujian and Zhejiang. With the lessons and experiences learned, on 1 July 2012, the National Development and Reform Commission (NDRC) introduced a nationwide progressive pricing reform for residential electricity use. According to the NDRC draft, electricity prices would follow a three-tiered residential rate structure for power usage. Taking Zhejiang province as one example, if a household consumes less than 2,760 kWh per year, the price is set at 0.538 RMB per kWh. If consumption is increased to 2,761–4,80 kWh, the price will increase by RMB 0.05 per kWh. The price could increase by RMB 0.30 per kWh if electricity consumption exceeds 4,800 kWh. The government expects that 70–80 % of Chinese households consume no more than the baseline level (110 or 140 kWh per month) and are charged the first-tier price for marginal consumption.

Resources such as water are usually underpriced to protect citizens and industries from inflation. However, such a pricing policy will not encourage efficient use of resources as a result of low cost. The government is increasingly aware of the need to charge higher water prices for the heaviest urban consumers to conserve diminishing resources and spur investment. After a few trials in some regions, the reform plan is expected take place nationwide by the end of 2015. Similar to the electricity price reform, the water price reform plan will also include a three-tiered pricing structure, based on water usage for households in all cities and some towns. Under the plan made by NDRC, the heaviest consumers—or top 5 % of households—will pay at least three times the base rate of water. The second tier will pay 1.5 times the base rate, while the lowest tier—roughly 80 % of urban households—would not be affected by the changes.

In the next section, we use the household data set to provide an overview of residential energy consumption. This is followed by a detailed analysis of household energy conservation behaviour.

[2]Yellow-label vehicles refer to those that fail to meet the European No.1 standard for exhaust emissions.

2.3 An Overview of CRECS 2012

2.3.1 Survey Design

The Department of Energy Economics at Renmin University of China (hereinafter referred to Renmin University) organised the first Chinese Residential Energy Consumption Survey (CRECS) from December 2012 to March 2013. Based on the Residential Energy Consumption Survey 2009 in the US (RECS-2009) and a few pilot surveys, a comprehensive questionnaire was designed to gather the energy and related information from individual households in reference year 2012. It comprised 324 questions and covered six main parts: household demographic characteristics; housing unit characteristics; kitchen and home appliances; space heating and cooling; transportation; energy consumption and expenditures. Each part includes detailed specific issues related to energy equipment, frequency of use, expenditure as well as energy use preference/attitudes.

As the investigators needed detailed parameters/information about various energy equipment and face-to-face interviews can take over one hour, we adopted a simple but effective sampling strategy to enhance data quality/reliability and lower refusal rate. In December 2012, around 120 undergraduate and graduate students from Renmin University were recruited to participate in the CRECS survey. These students were first requested to contact up to 20 candidate families within their local social network. The households that met the following criteria were surveyed. The households: (i) had to be able to provide electricity bills or records for 2012; (ii) were detached and individual households, rather than a collective or tenant family; (iii) used energy only for consumption purposes, rather than for production; and (iv) consisted of respondents who lived in their homes for more than six months in 2012. In addition, we did not select two or more families who lived in the same community to avoid homogeneity. Each respondent received a mobile phone with a prepaid card worth 50 RMB after they finished the survey. Each investigator received 50 RMB for one valid questionnaire as a payoff. At the end of the first stage, a total of 1,640 households were contacted to participate in this survey.

In January 2013, all students participating in the survey underwent a one-day training session to understand each question, grasp interviewing skills, and learn how to gather the geographic information via an equipped GPS device. The survey was implemented in the winter holiday from January to February 2013. The investigators communicated directly with the representative of the household or his/her spouse and filled out the questionnaire. The well-established personal relationships between respondents and investigators allowed for the double-checking of detailed information, such as the power of home appliances. A total of 1,542 households were enrolled with a high response rate of 94 % by the end of March 2013.

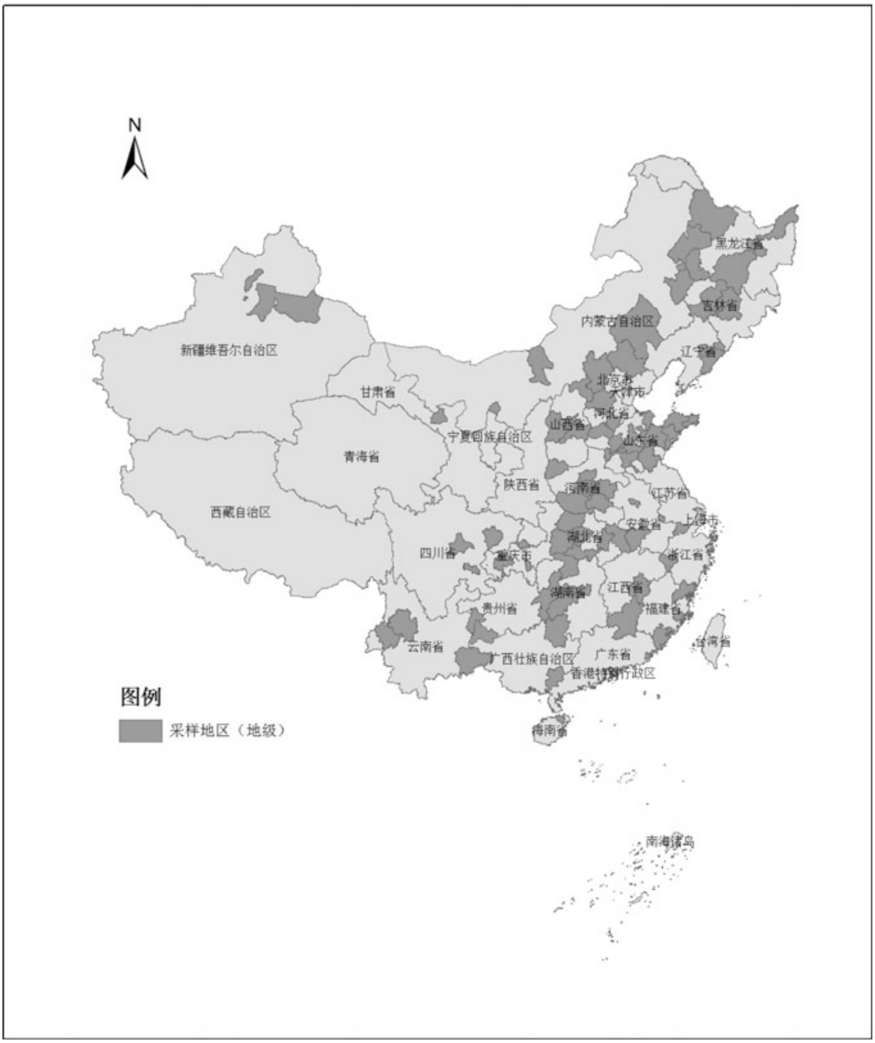

Fig. 2.4 Geographical distribution of sample coverage at the prefecture level. *Source* Authors' calculation

Random telephone interviews were conducted to examine the validity and consistency in the responses. This checking procedure left 1,450 observations for final analysis. As Fig. 2.4 shows, our sampled households covered 114 prefecture cities in

Table 2.1 Profile of household characteristics

Variables	Unit	CRECS-2012			NBS 2013[a]		
		Total	Urban	Rural	Total	Urban	Rural
Household size	Number of persons	2.65	2.57	2.95	3.02[b]	2.86	3.88
Male percentage	%	48.5	48.2	49.5	51.3[b]	50.6[b]	51.5[b]
Average age	Years	40.6	40.4	41.4	–	–	–
Proportion of employment per household	%	65.3	64.9	66.2	–	52.1	71.1
Schooling year	Years	10.2	11.2	6.8	8.8[b]	10.4[b]	7.6[b]
Income	10,000 Yuan	9.78	10.98	4.90	–	7.71	4.26
Expenditure	10,000 Yuan	5.28	5.50	4.33	–	6.39	3.73
Dwelling area	m^2	103.73	96.15	134.98	–	94.1	143.9

Source Zheng et al. (2014: Table 1)
Note CRECS China Residential Energy Consumption Survey; *NBS* National Bureau of Statistics; m^2 square metres
[a]NBS, *China Statistical Yearbook* (2013)
[b]NBS, *China Population and Employment Statistical Yearbook* (2012)

26 provinces in mainland China,[3] of which 80 % are in urban areas and 20 % in rural areas.[4]

Table 2.1 compares our sample with the official records. For household demographic characteristics, the average household size (2.65 people) was slightly less than the official number (3.02 people). The average age of family members was 40.6 years, of which 48.5 % were male and 65 % were employed. The average schooling was 10.2 years for all members, which is higher than the official statistics. In 2012, a typical household earned 97,800 yuan and the annual expenditure was 52,800 yuan. Moreover, the average living space for urban and rural households in our sample was 96 and 135 m^2, respectively. This is much closer to the NBS's number. Detailed information on the energy usage pattern is described in the later sections.

[3]The distribution is as follows: Anhui (42), Beijing (72), Fujian (47), Gansu (20), Guangdong (6), Guangxi (43), Guizhou (21), Hainan (2), Hebei (65), Henan (134), Heilongjiang (43), Hubei (138), Hunan (119), Jilin (76), Jiangxi (20), Liaoning (23), Inner Mongolia (40), Ningxia (20), Shandong (222), Shanxi (55), Shanghai (66), Sichuan (37), Tianjin (20), Xinjiang (26), Yunnan (29), Zhejiang (34), Chongqing (30).

[4]64 % in cities, 16 % in towns and 20 % in rural areas. To facilitate the comparison, we combined the cities and towns.

2.3.2 Measuring Household Energy Efficiency

There is no consensus on measurement of household energy efficiency. In the EU's comprehensive ODYSSEE programme, the indicator of household energy efficiency is defined as the unit consumption of households per dwelling, or per square metre. Depending on various research purposes, other detailed issue indicators can be defined for various end-use activities or appliances. In 1990, an overall index, ODEX, was established by weighting the energy efficiency of heating, water heating, cooking, refrigerators, freezers, washing machines, dishwashers and TVs. ODEX and its sub-index can be used to monitor and trace the energy efficiency progress for EU households (Lapillonne/Pollier 2014).

Acknowledging that energy efficiency is subject to the availability of data and is mixed with non-efficiency factors (i.e. structural, behavioural and economic differences), the USA's Energy Information Administration (EIA) has developed different indicators to meet various constraints and policy objectives. It further distinguishes between site energy and primary energy intensity. Primary energy is the amount of energy delivered to an end-user (e.g. residential housing unit) adjusted to account for the energy that is lost in the generation, transmission, or distribution of the energy. Site energy is the amount of energy delivered to an end-user without adjusting for the energy lost in the generation, transmission, and distribution of the energy (EIA 2000). Both types of energy intensity can be adapted to households, household members and converted to square feet.

We adopted energy intensity, that is, energy consumption per household, to measure energy efficiency. Households usually consume various types of energy for different end-use activities. Suppose there are i surveyed households, m types of energy activities and n types of energy. For the i-th family, $e_{i,m,n}$ is the amount of the n-th energy for m-th purpose. In our survey, we had seven types of energy: coal, natural gas, LPG, electricity, fuelwood, district heat, and solar power. The energy end-use activities included: cooking, space heating, space cooling, use of home appliances, and water heating.[5] Estimation of a household's energy consumption consists of two steps.

First, the consumption of various types of energy is estimated by the end-use activities. For example, for an electrical appliance, $e_{i,m,n}$ is determined by the output power, usage frequency and duration. The energy efficiency level and other technical characteristics (i.e. inverter air-conditioner) are taken into account by multiplying by a coefficient that is adjusted according to various national energy efficiency standards.[6] The calculation of energy for heating depends on the heating type. For the distributed heating systems, it is determined by two parameters. One is the heating period, which was collected from the questionnaires; the other is the average power

[5]Personal transportation is excluded to make our result comparable with other studies.

[6]For the energy efficiency standard of refrigerators, washing machines, televisions, computers, air-conditioners and electrical water heaters refer to GB 12021.2-2008, GB 12021.4-2004, GB 24850-2010, GB 28380-2012, GB 12021.3-2004 and GB 21519-2008, respectively.

or consumption rate, which can be obtained from the survey or related literature (Chen et al. 2013; Saidur et al. 2007). District heating is treated as one of the fuel sources for the central heating system user. Because fuel and technology information about the heating sources was not available, reference values (energy consumption per m^2 per heating season) were set up based on relevant energy efficiency standards for residential construction.[7] This was adjusted in accordance with the age of the building, window frame type, and insulation measures.

Second, various types of energy with different heat values need to be converted into a standard unit for comparison purposes. One can convert them into the standard coal equivalent (kgce) by multiplying by the conversion coefficient $coef_n$ for the n-th energy. Then the annual energy consumption for the i-th household can be measured as follows (Niu et al. 2012).

$$E_i = \sum_{m=1}^{M} \sum_{n=1}^{N} e_{i,m,n} \cdot coef_n \quad (2.1)$$

Also, the total energy consumption of n-th energy is

$$E_{i,n} = \sum_{m=1}^{M} e_{i,m,n} \cdot coef_n \quad (2.2)$$

Similarly, the total energy consumption for m-th activities is

$$E_{i,m} = \sum_{n=1}^{N} e_{i,m,n} \cdot coef_n \quad (2.3)$$

Based on Eq. (2.1), individual household energy consumption is first estimated. Energy usage by various type and purpose is computed from Eqs. (2.2) and (2.3), respectively.

As shown in Table 2.2, China's total household energy consumption was 1,426 kgce in 2012, which was less than several OECD (Organization for Economic Co-operation and Development) or economically developed countries. For instance,

[7]The energy conservation programme in the construction sector started in 1986. In the first stage, according to the energy conservation standard (heating residential buildings) (JGJ 26-86), it was required that energy consumption in residential construction be cut by 30 % on the basis of the 1980–81 level. In the second stage, the energy conservation standard (heating residential buildings) (JGJ 26-95), required that energy consumption in new construction be cut by 50 % on the basis of the 1980s level. In the third stage, China announced an energy efficiency standard for residential buildings in the hot summer and cold winter zones (JGJ134-2010) and other standards. The goal in this period was to attain 30 % energy savings on the basis of the second stage.

Table 2.2 Country comparison of household energy consumption

Country	Household energy consumption (kgce per household)
USA (2009)	3,227
Canada (2010)	3,287
EU27 (2008)	3,717
Germany (2008)	2,288
France (2008)	2,244
United Kingdom (2008)	2,353
China (2012)	1,426

Source USA (2009) comes from *U.S. EIA: 2009 RECS Survey Data*, at http://www.eia.gov/consumption/residential/data/2009/index.cfm?view=consumption; Canada (2010) comes from Natural Resources Canada: Statistics Canada's Report on Energy Supply-Demand in Canada (RESD), at http://data.gc.ca/data/en/dataset/27155507-0644-4077-9a97-7b268dfd8e58; EU 27 (2008) and member states' data comes from EU-ODYSSEE: Household Energy consumption, at http://www.indicators.odyssee-mure.eu/online-indicators.html; China (2012) is estimated by authors

the total household energy consumption in China in 2012 was approximately 44 % of that in the US in 2009, and 38 % of that in the EU 27 in 2008.[8]

2.3.3 Fuel Sources and End-Use Activities

The energy balance table of Chinese households in 2012 is shown in Table 2.3. In general, Chinese residents obtain energy mainly from seven types of sources, including district heating, electricity, fuelwood, gas, LPG, coal, and solar. District heating supplies 45 % of total energy needs, followed by natural gas and LPG. Electricity accounts for 15 % of the total energy supply, used for diverse purposes, e.g. household appliances (including lights), cooking, cooling, and water heating. Fuelwood, solar and coal are less important energy sources. Fuelwood is used for cooking and space heating. Solar is only used for water heating.

For the end-use purpose, space heating is the most energy-intensive, followed by cooking, and they account for 54 and 23 % of total energy consumption, respectively. Residents employ various types of energy for cooking, mostly gas, LNG and electricity; less so from fuelwood and coal. Water heating is the third largest energy user (14 % of total energy consumption). Almost 70 % of water heating uses gas and LNP, while the rest comes from electricity and solar energy. The energy demand from household appliances and space cooling was not as much as expected,

[8]The EU 27 includes: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, The Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and United Kingdom.

Table 2.3 Energy balance of Chinese households in 2012 (unit: kgce)

	Coal	Natural gas	LPG	Electricity	District heating	Fuel wood	Solar	Total
Cooking	16	135	56	51	–	69	–	327
Home appliance	–	–	–	102	–	–	–	102
Space heating	–	7	–	11	647	98	–	764
Water heating	–	111	29	27	–	–	38	205
Space cooling	–	–	–	28	–	–	–	28
Total	16	254	85	220	647	167	38	1426

Source: Authors' calculation

accounting for only 9 % of total consumption, which comes exclusively from electricity.

2.3.4 Comparison of Urban and Rural Residential Energy Consumption

There was a dramatic difference in energy consumption levels between urban and rural households (Table 2.4). The average household energy consumption in an urban household was 1,503 kgce/year, and per capita consumption was 651 kgce/year. In rural households, average total energy consumption was 1,097 kgce/year, and per capita consumption was 445 kgce/year. Energy consumption in urban households was about 1.4 times that of rural households.

Energy sources for urban and rural households were quite different: urban households obtain more energy from district heating, gas and electricity, and less from fuelwood, coal, LNG and solar. District heating accounted for 56 % of total energy consumed in urban households, but only 2 % in rural households. By contrast, rural households use fuelwood (used for space heating and cooking), accounting for as much as 59 % of total energy consumption. The share of electricity consumption was similar in urban and rural households: around 15 %.

Table 2.4 Comparison of urban and rural residential energy consumption by fuel type (unit: Kgce)

	Coal	Natural gas	LPG	Electricity	District heating	Fuel wood	Solar	Total
Urban	5	310	78	228	800	51	31	1503
Rural	62	22	115	165	21	648	65	1097

Source Authors' calculation

Natural gas was used much more in urban areas (20 vs. 2 %), reflecting the better network infrastructure, while LPG was used more in rural areas for cooking (5 vs. 10 %). Solar was used more often in rural households than urban households (2 vs. 6 %), reflecting the higher adoption rate of solar water heaters in rural areas.

2.4 Household Energy Conservation Opportunities and Challenges in China

2.4.1 Energy Efficiency for Space Heating

Since heating is the most energy-intensive end use for an average Chinese household, as shown in Table 2.3, it is naturally seen as a key area for energy conservation. We now look more closely at the energy efficiency of space heating.

China is a huge country with vast geographical and climatic variations. These result in different regional space heating systems. Since the 1950s, the urban areas in northern China have been supplied with central heating systems, but these were never made available in southern China. As shown in Table 2.5, 40 % of the surveyed households used central heating systems while another 39 % of households were not able to access central heating systems resorted to distributed heating. The average reported use area was 103.7 m^2 for the interviewed households, of which more than 80 % lived in apartment buildings. The use area of the living room, bedroom and study room was 28, 38 and 6 m^2, respectively. The proportion of households that installed plastic-steel windows frames and double glazing was 82 and 33 %, respectively.

Table 2.5 also shows that households with district heating had a much longer heating time (in terms of both length of heating season and heating time per day).

Table 2.5 Characteristics of space heating

	District heating	Distributed heating
Number of observations (%)	575 (40 %)	560 (39 %)
Sources or devices	Municipal network (63 %)	Portable electric heaters (35 %)
	Local boiler (21 %)	Air-conditioners (28 %)
	–	Heating stoves (28 %)
Fuel types	Not known	Electricity (67 %)
	–	Coal/fuelwood (29 %)
Average length of heating season	3.9 months	2.1 months
Heating time every day	All day long	4.3 h
Thermostat settings	No control	23 °C with people in door
	–	19 °C without people in door

Source Authors' calculation

Table 2.6 Average heating energy consumption per household in 2012 (kgce)

	Average	Median	S.D	Min	Max
District heating	1646.72	1423.53	1106.13	316.11	11380.05
Distributed heating	64.80	30.49	142.90	1.02	1456.27

Source Authors' calculation

Table 2.7 Energy efficiency of space heating system: district versus distributed (kgce/h.m^2)

	Average	Median	S.D	Min	Max
District heating	0.00756	0.00664	0.00453	0.00266	0.06024
Distributed heating	0.00942	0.00640	0.01313	0.00000	0.08281

Source Authors' calculation

In addition, they had a much larger heating area since they could not control the thermostat settings. This implies that district heating systems use much more energy than distributed heating systems. As presented in Table 2.6, the average energy consumption per household with the district heating system was as much as 25 times higher than that of a household with a distributed heating system.

However, if we control for the heating time and effective heating area, the story is different. We estimated the energy efficiency indicated by energy consumption per hour and per square metre (kgce/h.m^2)[9] and the result for the two heating systems is presented in Table 2.7.

Presently the district heating system will consume less energy than the distributed heating system for the same area and same time. That implies that the distributed heating system will need higher energy consumption to obtain a similar level of comfort.

2.4.2 Household Energy Conservation Activities

Activities related to household energy conservation can be divided into two categories: efficiency and curtailment activities (Gardner/Stern 1996). Efficiency activities are one-shot activities and entail the purchase of energy-efficient equipment, such as insulation and adoption of appliances with higher efficiency labelling. Curtailment activities involve repetitive efforts to reduce energy use, such as lowering thermostat settings (Abrahamse et al. 2005). Our survey reveals information on both types of activities.

The survey results show that 24 % of the respondents had insulated their windows or doors, mainly paying for this by themselves, while 7 % of the respondents

[9]Due to space constraints, the estimation method is not included here. Readers can refer to Guo et al. (2014).

Table 2.8 Energy consumption for heating and cooling: with insulation versus without insulation

Type	With insulation		Without insulation		T-stat
	% of sample	Energy use for heating and cooling (kgce)	% of sample	Energy use for heating and cooling (kgce)	
Windows and doors	24	716	73	772	0.93
Walls	7	812	90	751	0.94
Loft and pipeline	2	577	93	770	−1.32

Source Authors' calculation
Note We did not include respondents who did not know if they had insulation

Table 2.9 Energy efficiency labelling for home appliances

Efficiency labelling	Refrigerator (%)	Freezer (%)	Washing machine (%)	TV set (%)	Computer (%)	Water heater (%)	Air conditioner (%)
No label	36	38	52	77	84	65	42
First class	38	17	20	11	8	16	16
Second class	15	29	14	6	3	11	15
Third class	8	13	11	4	3	7	13
Fourth class	2	1	3	1	1	1	4
Fifth class	1	3	1	1	1	1	10

Source Authors' calculation

had wall insulation, most of which was financed by the government (Table 2.8). The average energy use for heating and cooling of households with insulation was lower than that of households without insulation, although not statistically different.

Regarding home appliances, the penetration rate of refrigerators, washing machines, televisions, computers, air-conditioners and water heaters was 89, 91, 120, 89, 113, and 84 %, respectively. Among all water heaters, 43 % were fuelled by electricity, followed by natural gas or LNG. Solar was another major fuel source with a high percentage of 25 %. All of the home appliances were required to have energy efficiency labelling since 2004. Our survey results showed that for the above appliances, the percentage of those labelled higher than Class 3 was 61, 44, 21, 15, 45 and 34 %, respectively.[10] The distribution of energy efficiency labels for home appliances is presented in Table 2.9.

[10]In China's energy label system, grade 3 indicates the average level. The smaller the grade number, the more energy efficient a product is.

On curtailment activities, we asked respondents to select between two types of behaviours. The first was whether they turned off the power after using an appliance. Over half of the respondents reported that they would turn off the power when they were not using the computer. 64 % of the respondents would unplug their chargers after the charging was done. The second behaviour was concerned with thermostat settings. When asked, respondents revealed that if the heating system could be individually controlled through a thermostat, they would set the temperature at 23 °C when there were people indoors, and at 19 °C when there was nobody indoors.

2.4.3 Information and Perception Towards Policy

There are three subsidy systems to promote the use of energy-efficient products, such as for the trade-in of old appliances; the purchase of energy-efficient products; and for home appliances in rural areas. Our survey shows that around one-fifth of refrigerator users obtained some purchase subsidies. The percentage of users who obtained subsidies for washing machines, televisions, air-conditioner units, and water heaters were 14, 16, 10 and 8 %, respectively. Fewer users got subsidies for computers. Also, about 29–34 % of users believed that subsidy policies, had affected their purchase decisions.

According to our survey, whether people can, and how they, access information on energy consumption and energy bills may also influence their behaviour. In our surveyed samples, 96 % of respondents installed a separate meter. Most of these meters were visible to the user, of which 80 % were located in the corridor and 16 % in the community. Among all respondents, 78 % of households knew their monthly electricity consumption and expenditure, out of which 68 % were informed by electricity bills and 23 % were informed by meter readers. The meter's type varies greatly. The proportion of users of smart meters, mechanical meters and IC card meters were 41, 36 and 4 %, respectively. This variation of meters lead to significant differences in tariff payments. Around 32 % of respondents prepaid their electricity bills and the rest paid after use. As for the payment frequency, 85 % of users paid their bills or recharged their IC cards every 1–3 months. More than half of the respondents paid at the local grid company's counter, and around 35 % settled their payment via bank or internet transfers.

The time-pricing electricity policy and the block electricity tariffs policy were the most important instruments changing people's behaviour. Our statistics show that around 38 % of respondents knew the time-pricing policy and 27 % knew whether it had been applied locally, lower than that of the tier-tariff policy (57 and 47 %, respectively). Only 13 and 27 % of the respondents got notifications from the grid company for the time-pricing and tier-tariff policies, respectively. The time-pricing policy was not available until residents applied for it. Successful applicants could enjoy a lower tariff at a non-peak time. After the investigator explained the benefit of the time-pricing policy, 30 % of respondents still did not want to apply for it since they were worried about the difficulty of the application process. The block electricity tariff was applicable to most of the residents while the quantity for each block could be adjusted according to the family size and conditions on the application. Around one-quarter of the respondents would not make changes since they were concerned about the complexity of the application process.

2.5 Conclusion

Based on the detailed CRECS-2012 dataset with 1,450 surveyed households, this study aimed to provide a brief overview of residential energy consumption in the residential sector in 2012. Our results show that the average household energy consumption was 1,426 kgce in 2012, which was lower than that of several OECD or economically developed countries. For instance, the total household energy consumption was only approximately 44 % of that in the US in 2009, and 38 % of that in the EU 27 in 2008.

The overview of energy consumption gives us some idea of where the energy goes. We found that among various activities, space heating was the most energy-intensive, consuming about 54 % of residential energy. In China, most energy used for space heating is provided by district heating. The thermostat setting cannot be controlled, and all rooms are supplied with heating for the entire heating season (an average of 3.9 months). One flaw in using this method is that the cost of district heating is estimated using construction area; therefore, there is no incentive for households to take measures to prevent energy leakage or conserve energy. In our survey, we found only a few households that applied energy conservation activities for walls and windows. This number is expected to be lower without government subsidies. Thus, if the government can reform the current heating pricing scheme by making the charge according to actual usage, rather than total construction area, we believe it will create great incentives for energy saving. Technically it is possible to improve the infrastructure and install individually controlled thermostat settings. Another argument for this lies in the popularity of the distributed heating system in Southern China. We found that given the same level of comfort, the energy efficiency of the district heating system is higher than that of the distributed efficiency. Therefore, considering comfort and energy conservation incentives, the ideal solution is to have a centralised heating system, with a decentralised and incentivised payment scheme.

Our second objective relates to a better understanding of energy conservation behaviour at the household level. Our data shows that Chinese households have taken some steps to conserve energy use. These activities include insulation of walls, doors and windows, and the purchase of more energy-efficient home appliances. However, the insulation adoption rate is still low in China. As for home appliances, the percentage of households purchasing energy-efficient appliances, such as washing machines, freezers and refrigerators, was higher than that for computers and TVs. This is possibly because the former are more energy-intensive, thereby giving households more incentive to own such appliances so as to reduce energy use. One interesting future research area is how to understand the determinants of home insulation behaviour and efficient home appliance adoption.

This chapter provides a brief overview of Chinese energy consumption at the household level using basic statistical survey data, and we have presented an overall picture of Chinese residential energy consumption patterns. However, further in-depth statistical analyses are required to identify the reasons behind the urban-rural differences.

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Chapter 3
Household Energy Saving in China: The Challenge of Changing Behaviour

Philip Andrews-Speed and Guo Ma

Abstract China's government has introduced a number of measures to constrain the rise of household energy consumption such as energy efficiency labelling, providing discounts on energy efficient appliances, and introducing tiered tariffs. But these steps alone may not succeed in changing household behaviours to the extent required. This chapter draws on the international literature on household energy behaviour, on a small number of surveys carried out in China and on our own study in Chongqing to explore the nature of the policy challenge facing China's government. A high degree of variability exists between different socio-demographic groups and, to a lesser extent, between regions with respect to knowledge, awareness, stated preferences and reported behaviours concerning energy saving at home. Further, the awareness-behaviour and value-action gaps are as well developed in China as in many other countries.

Keywords Energy-saving · Behaviour · Attitude · Household · China · Chongqing

3.1 Introduction

As part of its wider campaign to reduce national energy intensity, China's government has taken a number of steps to encourage energy saving by households. These include raising the minimum standards for electrical appliances, promoting energy efficiency labelling of appliances, encouraging the recycling of old appliances, offering discounts on selected high efficiency appliances and introducing

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tiered pricing for electricity and, more recently, for gas. Whilst these measures are necessary components of a strategy to encourage energy saving by households, they are insufficient by themselves. Current policies tend to be excessively focused on technological solutions and pay insufficient attention to behavioural factors (Yue et al. 2013). Likewise, the economic signals provided by tariffs and discounts are often inadequate to stimulate sustained behavioural change.

The challenge of changing the behaviour of individual citizens is one that is faced by governments of all industrialised and industrialising nations as they seek to reduce their country's energy intensity. The task is rendered more complicated by the variability of energy-saving behaviours between different societies and between different segments of society. Whilst the systematic study of household energy behaviour dates back more than 30 years in some Organisation for Economic Cooperation and Development (OECD) countries, such research is relatively new in China. English-language publications describing the results of systematic surveys only started to appear in any number since 2010.

The aim of this chapter is to identify the specific behavioural challenges facing China's government as it seeks to promote energy saving by households. The account begins with a review of the international literature on energy-saving behaviours, with a particular focus on the determinants of behaviour. This is followed by a review of the lessons identified by relevant studies in China published in English. The subsequent sections summarise the main findings of a survey carried out by the authors in Chongqing which provide additional insights.

3.2 The International Experience

Two types of energy-saving behaviour exist and they require distinct policy approaches. The first type comprises habitual actions which take the form of regular behaviours and routines that use energy. In many cases, these result in a loss of comfort and convenience. The second type involves specific decisions to purchase appliances with better energy efficiency characteristics, but that are likely to have a higher cost.

The policy instruments available to governments to change these behaviours are of three main types (Ek/Soderholm 2010). Economic instruments, such as raising energy prices or taxing energy consumption, can be used to discourage wasteful energy use. Conversely, grants and subsidies can promote investment in appliances or materials which can enhance energy efficiency or save energy in other ways. Administrative and regulatory instruments influence behaviour directly by forbidding or banning certain behaviours or products, by placing obligations on actors, or by setting standards for appliances. Whilst economic and administrative policy instruments provide a vital foundation, they may be insufficient by themselves to encourage greater energy saving on the part of the citizens. Information and education are usually needed not just to promote a general awareness of the need to save energy, but also to provide detailed information on how to save energy.

Information can indeed change attitudes and stated willingness to change behaviours, especially if the information is detailed, personalised and includes the financial benefits to the citizen (Owens/Driffill 2008; Abrahemse/Steg 2009; Ek/Soderholm 2010). However, information by itself may not prove effective. The impact of information on attitudes and behaviour of households and individuals has been shown to be highly dependent on the level of trust of citizens in different actors in the energy sector. Not only are different actors trusted to varying degrees, but a high degree of variability may exist within a community in the degree of trust placed in a particular actor (Mumford/Gray 2010; Ricci et al. 2010).

In the past, a large proportion of studies of household energy-saving behaviour have focused on or started with an assessment of the significance of socio-demographic variables such as income and age (e.g. Poortinga et al. 2003; Ek/Soderholm 2010). However, a growing body of research is showing that, although awareness and socio-demographic variables play a role in determining behaviour, other factors such as attitudes and behavioural norms may be more important (Barr et al. 2005; Owens/Driffill 2008; Abrahamse/Steg 2009). The neglect by policymakers of considering these factors in policy design results in continuing failure to persuade individuals to transform knowledge and attitude into action; these are, respectively the so-called awareness-behaviour and value-action gaps.

Lifestyle and behavioural norms add a further layer of complexity. Lifestyle determines the ease and willingness to purchase energy-efficient appliances or to curtail energy use (Tyler and Schipper 1990; Linden et al. 2006). Despite these constraints, individuals do seem to react to pressures from society by adjusting their behaviour in response to norms transmitted by social interaction (McFadden 2013), to receiving detailed information on the energy-saving behaviours of their peers (Allcott 2011), or to formal community-based projects (Moloney et al. 2010).

Identity provides the final links in the chain between awareness and behaviour. One type of identity relates to the role of the home in the life and identity of the household. The home plays a central role in the lives of many families and individuals, and this determines the nature of activities undertaken at home, the role of the home in the lives of the householders, and the degree to which the home is seen as an expression of the identity of the household (Mallett 2004). These factors, in turn, will shape household energy-use behaviours (Aune 2007).

Thus we see that attitudes, social norms and identity all play a key role in determining energy-saving behaviour, but the way in which these factors interact with each other and with socio-demographic variables to transform awareness into action is highly dependent on national or local culture, as on other circumstances such as resource endowment, the nature of the energy market, and history of energy shortages (Wilhite et al. 1996; Lenzen et al. 2006). As a consequence, no national government can just copy the policy approaches of other countries in order to promote energy-saving behaviour among households. Whilst the introduction of generalised market and administrative instruments is an essential first step, sustained success requires a deep understanding of the society in order to tailor and target policy instruments effectively. This is the challenge facing China's government today.

3.3 Household Energy Saving in China

China's government has recently been applying both economic and administrative instruments to encourage energy saving in the household sector. In 2009, a subsidy on the purchase of the most efficient air conditioners was introduced (National Development and Reform Commission 2009). This programme was so successful that the market share of energy efficient air conditioners rose from 5 to 80 % in just 2 years. As a result, the government terminated what was to be a 3-year programme a year early. A new subsidy programme covering air conditioners, washing machines, refrigerators and water heaters was introduced in May 2012.

In June 2010, the government launched a programme to buy back old household appliances, by giving a discount of 10 % on the price of new appliances. This programme covered televisions, computers, washing machines, air conditioners and refrigerators, and ran until the end of 2011 (Ministry of Commerce 2010). In addition, mandatory energy efficiency labelling of household appliances became widespread since its introduction in 2005, as did minimum energy performance standards (Zhou 2008; Zhou et al. 2011).

The government has traditionally constrained household electricity prices below the levels of other sectors, and this has dampened any affect that prices might have on energy use. A three-tiered pricing system for households was formally proposed in 2010 with the aim of providing stronger incentives to save energy for the larger users, and was implemented in 2012 after some adjustments (Sun/Lin 2013).

Published surveys from regions as diverse as Liaoning, Beijing, Tianjin and Jiangsu suggest that there is a widespread lack of knowledge among urban residents of individual households' energy use and energy bills, of how to save energy, of the need to save energy and of a sense of responsibility to save energy (Feng et al. 2010; Wang et al. 2011; Bai/Liu 2013; Yue et al. 2013). These authors concluded that government agencies need to provide more information and education on energy use and energy saving.

A number of studies have analysed the energy-saving and 'green' behaviours of urban households and their correlation with socio-demographic variables. Obstacles to buying energy-efficient appliances include the time and inconvenience involved, the shortage of suppliers with such appliances, and a lack of trust in energy efficiency labels and product standards (Feng et al. 2010; Wang et al. 2011). Income and education seem to be socio-demographic determinants of purchasing behaviour. Higher levels of education and income tend to lead to a greater willingness to spend more money to buy energy-efficient or 'green' appliances (Yue et al. 2013; Zhao et al. 2014). Income and age appear to correlate with a willingness to curtail energy use at home. Those with lower incomes seek to save money as do older individuals, many of whom have a long experience of energy shortages and frugality in China. Households with more people try to save energy. Conversely, wealthier and younger individuals appear to be less willing to sacrifice comfort and convenience (Wang et al. 2011; Yue et al. 2013; Chen et al. 2013; Zhao et al. 2014).

With respect to attitudes, a small number of studies have shown that environmental concern and energy-saving consciousness can shape energy-saving and other ‘green’ behaviours, and that these attitudes arise from relevant knowledge and awareness (Yu et al. 2011; Zhao et al. 2014). In a study of ‘low-carbon’ behaviour and awareness, Bai/Liu (2013) found that such ‘low-carbon’ behaviours appeared to be more pronounced than ‘low-carbon’ awareness, for the simple reason that economic incentives alone provided sufficient motivation for ‘low-carbon’ behaviour. But this study did not include energy saving which, as discussed, has insufficient economic incentive for many households.

We found no studies which explicitly examined the role of identity in shaping energy-saving behaviours in China; however there exists a small literature in English on the link between the home and individual identity in China that may have some bearing on energy saving. The privatisation of property in the early 2000s led to opportunities for large numbers of people to own and decorate their homes for the first time. New apartments and houses have no fittings or decorations and provide a great opportunity for self-expression. For the first time, individuals could separate themselves from their workplaces and exert their own preferences (Davis 2005). As well as providing a physical dwelling, these homes provide a focus for self-expression and self-realisation. In other words, the home forms an important part of the individual’s or family’s identity and, in particular, serves as a space to display personal success and wealth. In many cases, a man’s ownership of a home is a key requirement for marriage (Zhang 2010; Elfick 2011).

3.4 The Survey in Chongqing

Chongqing is a large industrial city in the south-west of China and was the site of a survey we conducted in 2009 and 2010. In order to reduce energy intensity, the government of Chongqing promulgated and implemented a number of measures arising from the energy-saving strategies of the national government. Most of these plans, laws and regulations applied to enterprises and to public bodies, though a number of measures were taken relating to household appliances, for example:

- Energy labelling of household appliances;
- Banning the sale of inefficient air conditioners;
- Discounts being offered by manufactures for certain energy-efficient household appliances; and
- Buy-back schemes for old household appliances.

Despite the large number of documents issued by the municipal government at the time of our survey, few made reference to household behaviour. Even a document entitled “Implementation Opinions on Energy Conservation Actions of All Citizens of Chongqing Municipality”, issued in August 2009, made very little mention of energy behaviours in the home. As will be revealed below, few steps, if any, seemed to have been taken to provide tailored advice or information to individual households, and residential electricity tariffs had not been raised during the 3 years preceding the survey.

In 2009 and 2010, we carried out a survey of citizens in the municipality of Chongqing in order to analyse the determinants of energy-saving behaviours. It was carried out in two phases: September–December 2009 and November 2010. The second phase was needed to address a serious shortage of middle-aged and older respondents in the first phase. The survey questionnaire comprised about 50 questions covering basic information on the profile of respondents as well as information on their knowledge, awareness, stated preferences and behaviours with respect to energy use and energy saving. The respondents were selected by using a combination of convenience sampling and judgement sampling methods at 11 locations; namely approaching the respondents in selected shopping centres, in residential areas, and in suburban and rural township areas between the city and countryside in the Chongqing Municipality. The survey produced a total of 246 valid questionnaires. Further information on the methodology and profile of the respondents has been presented in our earlier paper (Ma et al. 2013).

The analysis of the results of this survey falls into three parts: the first part focuses on awareness, knowledge and stated preferences with respect to energy saving in general, and summarises the results presented by Ma et al. (2013); the second part analyses stated preferences and reported behaviours relating to appliance purchase and energy use; and the third part identifies links between knowledge and attitude, on the one hand, and stated preferences and reported behaviours, on the other hand, as well as between stated preferences and reported behaviours.

3.5 Awareness, Attitudes and Stated Preferences in Chongqing

This part of the study examined three issues: the level of awareness and knowledge of energy saving; the sources of information received by households on energy saving, their trust in these sources, and the variation of these factors with socio-demographic indices; and the stated willingness of individuals to save energy at home, the options they would choose to save energy, and the variation of these factors with socio-demographic indices. The detailed results and analyses have been presented by Ma et al. (2013) and here we summarise the key findings.

The survey showed that citizens of Chongqing had a relatively good awareness of the general energy challenge facing China and a relatively good knowledge of electricity as it relates to household appliances. In contrast, they seem to have a low awareness of government polices relating to energy saving, except for those they experience when buying appliances, such as labelling and discounts. They also lacked detailed guidance on how to save energy in the home. The highest degree of awareness of government policies was among younger individuals and among those from wealthier and more highly educated families.

Though the need for citizens in Chongqing to receive more information and guidance was clear, how this should be provided is not straightforward for a number of reasons. First, most individuals receive information on energy policies and energy saving from sources and through media which are rather remote from the individual household, mainly from the government and through television and newspapers. Information directed at individual households and supplied by actors which directly interact with households, such as the electricity supply companies or the local community centres, was much less common. This contrasts with countries such as the United Kingdom where power supply companies have the legal obligation to reduce residential energy consumption and therefore make contact with households through telephone calls, leaflets and even visits to homes.

The survey revealed a high degree of heterogeneity among the citizens of Chongqing with respect to the type of media they use, the sources of information they rely on, and their level of trust in these sources of information. This is consistent with studies elsewhere that show that different segments of the population need to receive information in different forms and through different media (Harris et al. 2010). As a consequence, any programme to disseminate information on energy saving to households in China more effectively will need to be designed to take into account this heterogeneity by using different approaches for different social groups.

A further complication lies in the level of trust in different actors. The greatest trust appeared to be placed in those actors furthest from the household, namely the Central Government and the government of Chongqing. The next most trusted sources were colleagues, friends and family—though these individuals were clearly closer to the household than the government, the survey suggested that these groups were unlikely to be well informed on government policies or on steps which could be taken to save energy in the home. The level of trust in power companies, retailers and community centres, which have the relevant information and lie closer to the household than the government, was much lower. That is to say, those agents which were in the best position to provide specific advice to households were not as well trusted by citizens as those agents that are more distant.

A further challenge lay in the heterogeneity of norms and stated preferences relating to changing behaviours that was revealed by the survey. Younger individuals and those from households with a higher level of education were more likely to agree that they should change their behaviours. For the respondents as a whole, economic pressures were clearly perceived as likely to affect behaviour, with discounts on energy-efficient appliances and electricity price rises being seen as the strongest drivers. Yet the recognition of these pressures was accompanied by a general unwillingness to have a smaller quantity or size of appliances; that is to say, levels of comfort or convenience were not readily compromised. The nature of the stated preferences in these respects showed some variability, with wealthier individuals being more prepared to invest in energy-saving appliances, younger individuals focusing on using appliances more efficiently, and the older and less educated preferring to buy smaller appliances or use them less frequently.

3.6 Appliance Purchase and Energy-Use Behaviours in Chongqing

The survey revealed a relatively consistent pattern of stated priorities applied when purchasing new appliances of different types (Table 3.1). Brand and price were consistently the top two priorities, with energy consumption being third. 77.6 % of the respondents placed energy consumption in their top four priorities, and 51.3 % in their top three priorities. The advice of sales assistants was not ranked highly and the availability of credit was the least important consideration. Household income appeared to be a significant determinant of the ranking of priorities (Table 3.2). Households with higher levels of income tended to rank brands and performance labels more highly, whilst the lower income households favoured energy consumption, price and the availability of credit. In the case of refrigerators, energy consumption was also more important for larger households.

Respondents were asked to identify those factors which would persuade them to buy a smaller or more efficient appliance the next time (Table 3.3). The provisions of discounts ranked top for all three types of appliance and was favoured by households with more individuals aged between 18 and 30 years (Table 3.5)—in other words, preferred by households composed of young adults with less spending power than their older counterparts. This group also tended to rank higher salary as a significant factor. The availability of more information on energy saving was also important. Higher electricity prices ranked lowest of the four factors, but was high in the case of air conditioners, no doubt because they can consume the largest quantity of electricity over the year (Table 3.4).

Our survey of energy-use behaviours focused on air conditioners, in both cooling and heating modes (Table 3.5). The aim was to identify correlations between behaviours and socio-demographic variables. In general, the households with higher incomes used air conditioners to a much greater extent—for more months per year (cooling only); more hours per day and per night (cooling only); in more rooms (heating and cooling)—and they were also less likely to turn off the air conditioner when leaving a room. A similar pattern with respect to cooling was apparent in households with a larger number of individuals with tertiary education. The age profile of the household also appeared to be significant and most probably related to the varying degrees of tolerance of heat and cold, with the older requiring more heat in winter and the younger wanting more cooling in summer. The habit of turning off the air conditioner when leaving a room also varied with age, the older being more likely to, due to thriftiness accrued through life experience.

Table 3.1 Stated ranking of priorities that formed the basis for the most recent purchase of different electrical appliances

Rank	Brand	Price	Energy consumption	Size	Label: performance	Latest model	Sales assistant	Credit
Refrigerator								
1st	**61.1**	24.9	7.8	2.1	4.1	0	0	0
2nd	19.7	**38.9**	17.7	8.3	11.4	2.6	0.5	1
3rd	9.8	23.3	**34.4**	13	11.4	6.3	1.6	0
4th	6.7	9.8	20.3	**25.4**	18.7	9.9	4.2	6.3
5th	2.1	1.6	11.5	20.1	**26.9**	18.8	13	6.3
6th	0	0.5	4.2	17.6	17.1	**33.3**	18.8	7.3
7th	0	0.5	3.1	7.8	6.7	24.5	**43.8**	13.5
8th	0.5	0.5	1	5.7	3.6	4.7	18.2	**65.6**
Total responses	193	193	192	193	193	192	192	192
Air conditioner								
1st	**56**	25.3	12.8	4.7	1.3	0	0	0
2nd	22	**41.3**	20.1	9.4	2.7	4	0.7	0
3rd	14	20.7	**33.6**	16.8	10.1	3.4	0	0.7
4th	7.3	8.7	20.8	**32.2**	16.1	8.1	4	4
5th	0	2	4.7	24.2	**20.8**	22.1	15.4	11.4
6th	0.7	0.7	3.4	8.1	19.5	**33.6**	24.2	9.4
7th	0	1.3	3.4	2.7	17.4	23.5	**38.9**	12.1
8th	0	0	1.3	2	12.1	5.4	16.8	**62.4**
Total responses	150	150	149	149	149	149	149	149
Washing machine								
1st	**59.5**	25.7	5.3	5.3	3.3	0	0	0
2nd	22.9	**42.1**	16.4	7.2	7.9	2.6	0	0.7
3rd	11.8	22.4	**29.6**	14.5	15.1	6.6	0.7	0.7
4th	4.6	5.3	26.3	25.0	17.8	9.9	6.6	5.9
5th	1.3	2	9.2	**27.0**	**19.7**	20.4	11.8	9.2
6th	0	2	6.6	11.2	16.4	**29.6**	24.3	9.9
7th	0	0.7	5.9	7.2	9.9	26.3	**38.2**	11.8
8th	0	0	0.7	2.6	9.9	4.6	18.4	**61.8**
Total responses	153	153	152	152	152	152	152	152

Numbers against each rank (1st–8th) indicate the percentage of respondents that assigned that ranking to the particular priority. *Source* Authors' calculations

Note Each individual was asked to rank in order 1–8 the eight given priorities for choosing a particular appliance; "label performance" refers to the presence of a label indicating superior performance; "credit" refers to the availability of credit; bold numbers indicate the highest frequency of ranking for that particular priority

Table 3.2 Correlations between selected profile parameters and the relative ranking of priorities that formed the basis for the most recent purchase of the three household appliances

Variable	Co-variable	Appliance	Pearson's R	Sign.	Spearman	Sign.
Brand	Household income	Fridge	+0.149	0.039**	+0.163	0.023**
		AC	+0.225	0.006**	+0.227	0.005**
		WM	+0.195	0.015**	+0.183	0.024**
Price	Household income	Fridge	−0.094	0.193	−0.177	0.014**
Energy consumption	Household income	AC	−0.103	0.212	−0.159	0.053*
		WM	−0.172	0.034**	−0.182	0.025**
Label: performance	Household income	Fridge	+0.158	0.028**	+0.151	0.036**
		WM	+0.199	0.014**	+0.145	0.076*
Availability of credit	Household income	WM	+0.155	0.057*	+0.126	0.123
			Pearson Chi-sq	Sign.		
Energy consumption	No. in household	Fridge	+75.455	0.009**		

Source Authors' calculations
Note **significant at 95 % level; *significant at 90 % level

Table 3.3 Factors which respondents stated would persuade them to purchase a smaller or more efficient appliance next time

	Discount	More information	Higher salary	Higher electricity price	Nothing
Refrigerator					
Yes (%)	64.3	45.9	27.1	19.0	3.2
No (%)	35.7	54.1	72.9	81.0	96.8
Air conditioner					
Yes (%)	57.9	42.6	31.9	25.0	2.8
No (%)	42.1	57.4	68.1	75.0	97.2
Washing machine					
Yes (%)	63.5	43.4	30.1	20.1	3.2
No (%)	36.5	56.6	69.9	79.9	96.8

Source Authors' calculations

Table 3.4 Correlation between profile parameters and factors which respondents stated would persuade them to purchase a smaller or more efficient appliance the next time

Parameter	Appliance	Variable	Pearson Chi-sq	Sign
No. in household aged 18–30	Fridge	Discount	+16.396	0.001**
	Fridge	Higher salary	+8.161	0.043**
	AC	Discount	+9.788	0.020**
	AC	Higher salary	+6.494	0.090*
	WM	Discount	+20.885	0.000**

Source Authors' calculations
Note **significant at 95 % level; *significant at 90 % level

Table 3.5 Correlations between selected profile parameters and the use of air conditioners for heating and cooling

Parameter	Cooling/heating	Pearson R	Sign.	Spearman	Sign.
Months per year					
Household income	Cooling	+0.162	0.015**	+0.162	0.016**
Hours per day					
Household income	Cooling-day	+0.202	0.003**	+0.196	0.004**
	Cooling-night	+0.225	0.001**	+0.214	0.001**
Number of rooms					
Household income	Heating-night	+0.194	0.020**	+0.196	0.018**
	Heating-day	+0.146	0.075*	+0.149	0.070*
	Cooling-day	+0.368	0.000**	+0.351	0.000**
	Cooling-night	+0.442	0.000**	+0.431	0.000**
Turn off AC					
Household income		−0.195	0.003**	−0.167	0.011**
		Pearson Chi-sq	Sig		
Months per year					
No. of individuals aged over 60	Heating	+23.699	0.005**		
No. of individuals with Tertiary education	Cooling	+17.83	0.023**		
Hours per day					
No. of individuals aged over 60	Heating-night	+17.273	0.008**		
No. of individuals with Tertiary education	Cooling-day	+15.552	0.049**		
	Cooling-night	+33.886	0.000**		
Number of rooms					
No. of individuals aged over 60	Heating-day	+53.202	0.000**		
No. of individuals aged 18–30	Heating-day	−18.120	0.006**		
	Cooling-day	+15.294	0.018**		
No. of individuals aged under 18	Cooling-day	+9.894	0.042**		
No. of individuals with Tertiary education	Cooling-night	+30.801	0.000**		
Turn off AC					
No of household members aged over 60		+11.762	0.008**		
No of household members aged 30–60		−8.321	0.04**		

Source Authors' calculations
Note **significant at 95 % level; *significant at 90 % level

3.7 Awareness-Behaviour and Value-Action Gaps in Chongqing

The final stage of our analysis sought to understand the extent of the awareness-behaviour and value-action gaps by identifying significant relationships between knowledge or attitudes on the one hand, and stated preferences and behaviours on the other, as well as between stated preferences and reported behaviours.

Our analysis suggests that knowledge does seem to have some bearing on stated intentions and reported behaviours, though the correlations are not always significant at the 95 % level (Table 3.6). Those who have more knowledge were more likely to say they will spend more money to buy a more efficient appliance and they ranked energy consumption more highly in their most recent purchase of a washing machine and refrigerator, but not of an air conditioner. They were more likely to replace their washing machine and refrigerator more frequently, which would allow them to purchase a more efficient model. Those with more knowledge also tended to use the washing machine only when it was full, thus saving energy, and to set the air conditioner to a lower temperature when in cooling mode. However, they also reported using the air conditioner for heating during more months each year, and showed a relatively low tendency to turn off the air conditioner when leaving the room. No significant correlations were found between level of knowledge and any other stated intentions or reported behaviours.

Some correlations were also evident between attitudes to energy saving and stated preferences and behaviours (Table 3.7). Those who agreed that they as an individual should change their energy-use behaviours were more likely to have stated that they would use appliances more efficiently; reported that they do use air conditioners for fewer months of the year and in fewer rooms during the day; and that they replaced the air conditioner more often. Those who agreed that people of China and of the world should change their behaviours tended to have stated that they would use appliances more efficiently.

Some links between stated preferences and reported behaviours can also be seen (Table 3.8). Those individuals who stated that they would use appliances less frequently or more efficiently showed a tendency to use daytime and night-time cooling for fewer hours per day, to turn off the air conditioner when leaving a room, and to use the washing machine only when it was full. But those who stated that they would use their appliances more efficiently were setting their heating systems at higher temperatures. With respect to purchase behaviours, we identified few links with stated intentions. A positive correlation existed between stated willingness to spend more money on energy efficient appliances and the importance of brand in their most recent purchase of a refrigerator. Conversely, price was not such an important consideration. But we found no correlation between stated willingness to spend more money on energy-efficient appliances and energy consumption being an important consideration in appliance purchase.

Table 3.6 Correlations between knowledge and stated preferences and behaviours

		Pearson R	Sign.	Spearman	Sign.
Knowledge that people can save energy in their homes					
Stated preference					
Spend more money on more efficient appliances		+0.114	0.075*	+0.121	0.058*
Buy smaller appliances		−0.114	0.074*	−0.121	0.057*
Stated behaviour	*Appliance*				
On what basis did you buy appliance: energy consumption?	Washing machine	+0.2	0.013**	+0.227	0.005**
	Fridge	+0.115	0.112	+0.152	0.035**
How often do you replace appliance?	Fridge	+0.114	0.114	+0.134	0.063*
	AC	+0.144	0.058*	0.165	0.029**
How many months per year use?	AC: heating	+0.125	0.124	0.142	0.079*
Use only when full?	Washing machine	+0.114	0.079*	0.104	0.109
Turn off when leaving room?	AC	−0.119	0.07*	−0.118	0.072*
Knowledge that energy is a challenge for China					
Stated behaviour					
AC temperature setting, heating, daytime	AC	−0.166	0.042**	−0.189	0.020**

Source Authors' calculations
Note **significant at 95 % level; *significant at 90 % level

Table 3.7 Correlations between attitude and stated intentions and behaviours

		Pearson R	Sign.	Spearman	Sign.
Respondent as an individual should change their behaviour					
Stated intention					
Buy smaller appliances		−0.128	0.045**	−0.125	0.05*
Use appliances more efficiently		+0.139	0.031**	+0.145	0.024**
Stated behaviour	*Appliance*				
Frequency of replacing appliances	AC	+0.215	0.004**	+0.205	0.007**
Months of use AC cooling	AC	−0.153	0.020**	−0.087	0.188
Number of rooms run AC daytime cooling	AC	−0.184	0.007**	−0.90	0.090*
People of the world should change behaviour					
Stated intention					
Use appliances more efficiently		+0.170	0.008**	+0.169	0.008**
People of China should change behaviour					
Stated intention					
Use appliances more efficiently		+0.165	0.010**	+0.150	0.019**

Source Authors' calculations
Note **significant at 95 % level; *significant at 90 % level

Table 3.8 Correlations between stated preferences and reported behaviours

Behaviour	Appliance	Pearson R	Sign.	Spearman	Sign.
Will use appliances less frequently					
Hours per day use of appliances	AC: cooling-daytime	–0.114	0.093*	–0.115	0.091*
Turning off when leaving room	AC	+0.132	0.045**	+0.132	0.045**
Use only when full	Washing machine	+0.131	0.044**	+0.131	0.044**
Will use appliances more efficiently					
Hours per day use of appliances	AC: cooling-night	−0.162	0.017**	−0.161	0.018**
Temperature setting	AC: heating-day	+0.179	0.030**	+0.155	0.061*
	AC: heating-night	+0.139	0.096*	+0.143	0.085*
Will spend more money on energy efficient appliances					
Priority on price	Fridge	−0.168	0.02	−0.17	0.018**
Priority on brand	Fridge	+0.133	0.065	+0.135	0.06*

Source Authors' calculations
Note **significant at 95 % level; *significant at 90 % level

3.8 Conclusions: Policy Implications

Policy programmes to reduce or constrain energy use at home have to address a number of complexities such as socio-demographic variability, psychographic factors and lifestyle preferences, which together act to create gaps between awareness and attitudes on the one hand and behaviour on the other. This difficulty is exacerbated by the variability of different cultures and societies, and so no government can just copy the policy approach of another. National policymakers need to develop a deep understanding of their citizens in order to develop an appropriate range of policy instruments. Whilst China's government has deployed a number of economic and administrative instruments to constrain household energy use that have met with some success, progress is unlikely to be sustained unless the government develops a more sophisticated set of policies.

The surveys of Chinese citizens reported in this chapter showed that a high degree of variability existed between different socio-demographic groups and, to a lesser extent, between regions with respect to knowledge, awareness, stated preferences and reported behaviours concerning energy saving at home. Income, age, level of education and number of individuals in the household were commonly reported factors, though with varying degrees of significance. A frequent theme was that economic incentives, such as discounts on energy-efficient appliances and higher electricity tariffs, were most likely to motivate energy-saving behaviours. However, the obstacles to changing behaviour included a general unwillingness to sacrifice comfort, the inconvenience in trying to purchase better appliances, a lack of trust in key actors, and a lack of knowledge about how to save energy. In addition, energy consumption characteristics were rarely the highest priority when purchasing a new appliance. One reason may be that the energy efficiency label provides insufficient information on the long-term cost benefits of the appliance.

The few existing studies that examine the links between awareness, specific knowledge, attitudes and behaviour in China show that these links are relatively weak and that the awareness-behaviour and value-action gaps are as well developed in China as in many other countries. Whilst a significant proportion of people are generally aware of energy and climate challenges, their knowledge of specific government policies and of how to save energy at home appears to be relatively low.

The policy implications for China's government, as it seeks to promote household energy saving, are far reaching. Of greatest importance is the need to create new ways to deliver information at a local level on how to save energy at home and of the importance of energy saving. This localisation of information provision should meet three requirements. First, it should provide information and advice that is appropriate to the general characteristics of the community and in a way which can be tailored to the needs of individual households. Second, the media used for the dissemination of this information should also be chosen carefully, depending on the demographics of the community. Third, the agencies providing the information and advice will need to make efforts to build the trust of households. One way to approach these tasks is to develop community-based initiatives that combine information, education and advice, as well as feedback on individual household performance.

The second major implication is that different households will choose different ways to save energy at home and will respond positively to different types of incentives. As a consequence, government agencies at national and sub-national levels should deploy a wider range of economic instruments to ensure that most segments of the population take action to save energy. The three-tiered pricing system for households introduced in 2012 reflects a new approach, but is unlikely to achieve much in the short term until the structure is changed to make the majority of householders, especially those with air conditioners, pay a higher tariff. In early 2014, the government announced that it would start to introduce time-of-day pricing for household electricity. If structured appropriately, this step could dramatically reduce peak loads, but the installation of new meters across the major urban areas will take several years.

A final challenge relates to the issue of identity and the home. In many cultures, the home forms a key part of an individual's identity, but in China this appears to be very pronounced. This results in effort and expenditure being directed at individualised appearance and comfort, and rather less directed at practicality and energy saving. This attitude to the home is likely to prove quite resistant to change, and systematic research is needed into this phenomenon.

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Chapter 4
Prospects for Energy Savings and GHG Emissions Reductions from Energy Efficiency

Youguo Zhang

Abstract Rapid industrialisation and urbanisation are expected to continue in China. Energy efficiency improvement (EEI), namely reducing the national energy intensity, is a very important energy conservation and carbon emission reduction index for China. China has adopted measures to improve energy efficiency and achieve the objectives of the 11th Five Year Plan. (The central government of China planned to reduce the GDP-based energy intensity of China by 20 % in 2006–10.) In 2005, an input-output structural decomposition analysis showed a decline in energy savings and emission reductions (ESER) in the energy sector of 33 and 34 % respectively, in the total production-related energy consumption and carbon emissions. Further, by using a dynamic computable general equilibrium model for China, my research team and I analysed the potential effect of EEI on ESER over the period of 2013 to 2030. Based on the decrease in energy intensity from 2010 to 2030, we considered three scenarios: baseline (decrease by 9 %); moderate (decrease by 44 %); and ambitious (decrease by 68 %). Compared to the baseline scenario, EEI in the moderate scenario will gain 36.1 billion tons of coal equivalent standard (BTce) of energy savings and 21.0 billion tons of carbon equivalent (BTC) carbon emission reductions for China. The ambitious scenario will result in 48.4 BTce of energy savings and 28.2 BTC of carbon emission reductions for China. More than half of the ESER are from electricity and heat production and distribution sectors.

Keywords Energy efficiency · Energy conservation · Carbon mitigation · Computable general equilibrium model · Input-output analysis

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4.1 Introduction

Energy efficiency (EE), as an important index that measures the quality of development, has been emphasised by the Chinese government for many years. Accompanied by rapid economic growth, the energy consumption and carbon emissions of China are ranked among the top in the world. The importance of EE to the Chinese government has also been raised. According to the 11th Five-Year Plan of China, decreasing the amount of energy consumption per unit of gross domestic product (GDP), namely the GDP-based energy intensity, is the constraint index for development that deals with the increasingly serious energy security problem and emissions in China. Though energy intensity and EE are not exactly the same, the GDP-based energy intensity is regarded as an index for measuring the EE at the national level by the Chinese government.[1] Therefore, reducing energy intensity is the same as energy efficiency improvement (EEI) at the national level for the Chinese government. What are the historical and potential effects of EEI on energy savings and emission reductions (ESER)? We attempt to answer this question in this chapter.

Several studies have analysed the historical contribution of EEI to ESER in China. Most (such as Wu et al. 2005; Liu et al. 2007; Zhang et al. 2011) adopt the index decomposition analysis (IDA), but some (e.g. Zhang 2009, review in Su/Ang 2012) employ the input-output structural decomposition analysis (SDA). The advantage of the former group of studies is that they can be supported by annual economic and energy consumption data, whereas the latter group consider the deep linkage between industries (Ang 2004). However, regardless of the method used, almost all the studies report the important historical contribution of EEI to ESER in China.

A number of studies also focus on the potential effect of EEI on ESER in China. Combining the Asia-Pacific Integrated Model (AIM) and a computable general equilibrium model (CGE), Xu et al. (2007) find that the EEI target of China for the 11th Five-Year Plan could not be realised under the reference scenario. It could only be achieved if the necessary policies, such as investment, subsidy, and energy tax are implemented. Using the CGE model, Liang et al. (2009), Zha/Zhou (2010), and Li/Lu (2011) report significant rebound effects of end-use EEI. In addition, many studies, such as Wang et al. (2009), Dai (2011), Lu et al. (2013), Zhang et al. (2013), and Zhang (2013), simulate potential effects of carbon emission intensity constraint on ESER in China by using CGE models.

To our knowledge, few studies focus on the potential effect of EEI in the 12th Five-Year Plan or beyond. This chapter, thus attempts to analyse the historical contribution of EEI to ESER in China in the 11th Five-Year Plan and assess its potential effect in the near future and medium-term. The rest of the chapter is organised as follows. Section 4.2 analyses the historical contribution of EEI in the

[1]See, for an example, *The Special Medium-Long Item Program of Energy-saving* issued by the State Development and Reform Commission of China.

11th Five-Year Plan based on SDA; Sect. 4.3 simulates the potential effect of EEI from 2007 to 2030; Sect. 4.4 discusses the opportunities and challenges for EEI in China; and Sect. 4.5 concludes the study.

4.2 Historical Contribution of EEI to ESER in the 11th Five-Year Period

4.2.1 The Decomposition Method

We can write total energy consumption f in production as

$$f = \mathbf{e}^{\mathrm{T}}\mathbf{L}\mathbf{s}y \tag{4.1}$$

where, $\mathbf{e}$ is sector energy intensity vector, whose element e_i represents the ratio of energy consumption and output of sector i; $\mathbf{L}$ is the Leontief inverse; $\mathbf{s}$ is the final demand vector, whose element s_i represents the final product from sector i; y is the total final demand; the superscript "T" means the transpose of a vector or matrix. Let $\boldsymbol{\xi} = \mathbf{e}^{\mathrm{T}}\mathbf{L}$, whose element ξ_i represents the energy multiplier of sector i. Further, we can represent total carbon emissions in production as

$$c = \boldsymbol{\beta}^{\mathrm{T}}\hat{\mathbf{e}}\mathbf{L}\mathbf{s}y \tag{4.2}$$

where $\boldsymbol{\beta}$ is the vector of carbon emissions coefficient of fossil fuels, whose element β_i represents the ratio of carbon emissions to energy consumption of fuel i; $\hat{\mathbf{e}}$ is the diagonal matrix of $\mathbf{e}$.

According to Eq. (4.1), we can use the two polar decomposition technique (Fujimagari 1989; Betts 1989) to represent the change of energy consumption between time points 0 and 1 as

$$\begin{aligned}\Delta f = f_1 - f_0 = {} & \left(\Delta\mathbf{e}^{\mathrm{T}}\mathbf{L_1}\mathbf{s_1}y_1 + \Delta\mathbf{e}^{\mathrm{T}}\mathbf{L_0}\mathbf{s_0}y_0\right)/2 + \left(\mathbf{e_0^{\mathrm{T}}}\Delta\mathbf{L}\mathbf{s_1}y_1 + \mathbf{e_1^{\mathrm{T}}}\Delta\mathbf{L}\mathbf{s_0}y_0\right)/2 \\ & + \left(\mathbf{e_0^{\mathrm{T}}}\mathbf{L_0}\Delta\mathbf{s}y_1 + \mathbf{e_1^{\mathrm{T}}}\mathbf{L_1}\Delta\mathbf{s}y_0\right)/2 + \left(\mathbf{e_0^{\mathrm{T}}}\mathbf{L_0}\mathbf{s_0}\Delta y + \mathbf{e_1^{\mathrm{T}}}\mathbf{L_1}\mathbf{s}_1\Delta y\right)/2\end{aligned} \tag{4.3}$$

where, "Δ" represents changes of variables. The first term on the right side of Eq. (4.3) represents the effect of changes in sectoral EEs on the change of energy consumption; the second term represents the effect of changes in input structure; the third term represents the effect of changes in final demand composition; and the fourth term represents the effect of change in total demand, which can be called the scale effect.

We used the input-output table compiled by the National Bureau of Statistics of China (NBSC) for 2002, 2005, 2007, and 2010, to conduct the empirical analysis. Considering the price differences between the years, we adjusted the tables for 2002, 2007 and 2010 by using 2005 prices. We aggregated the 2002, 2005 and

2007 input-output tables into 41 sectors because the 2010 input-output table comprised only 41 sectors. At the same time, we used the method in Zhang (2009) to separate imports from intermediate input and final demand to compile the import-non-competitive input-output tables. The energy consumption data were obtained from various issues of the *China Energy Statistical Yearbook*. The sector carbon emissions were estimated using the method described in Zhang (2009).

4.2.2 Decomposition of Changes in Energy Consumption and Carbon Emissions in the 11th Five-Year Period

The EEI target of the 11th Five Year Plan was to reduce the GDP-based energy intensity in China by 20 % from 2005 to 2010. To realise the target, policies were designed and implemented. These policies included three main categories, namely, laws and regulations, economic instruments, and administration instruments. Many government departments were involved in achieving the EEI target; thus, the energy intensity decreased by 19.1 % from 2005 to 2010.

Table 4.1 shows the empirical results of the decomposition analysis on the changes in energy consumption and carbon emissions in the 11th Five-Year period. EEI reduced the energy consumption effectively. The energy savings as a result of the decreasing sector energy intensities were approximately 33 % of the total energy consumption in 2005. However, the scale effect as a result of the increasing total final demand far exceeded the EEI effect in the entire period. The changes in input structure also increased the energy consumption in all periods. The changes in final demand composition are helpful in conserving energy during the entire period, but may have caused the energy consumption to increase from 2005 to 2007.

Similarly, EEI reduced carbon emissions effectively. The reduction in carbon emissions from EEI was approximately 34 % of the total carbon emissions in 2005. The increase in carbon emissions resulted from the increased total final demand, and the changes in input structure also far exceeded the reduction from EEI. The changes in carbon coefficients counted against energy savings in all periods except 2005 to 2007. The changes in the final demand composition were helpful in conserving energy in the whole period but they caused an increase in energy

Table 4.1 Structural decomposition of changes in energy consumption and carbon emissions

	Changes in energy consumption (MTce)					Changes in carbon emissions (MTC)					
	Δe	ΔL	Δs	Δ*y*	**Total**	Δβ	Δe	ΔL	Δs	Δ*y*	**Total**
2002–05	−496	499	59	607	**669**	9	−295	311	47	376	**448**
2005–07	−439	37	48	757	**402**	−12	−280	33	34	476	**250**
2007–10	−265	91	−55	782	**553**	48	−176	66	−38	497	**396**
2005–10	−704	127	−7	1539	**955**	35	−456	99	−4	973	**646**

Source Authors' calculation

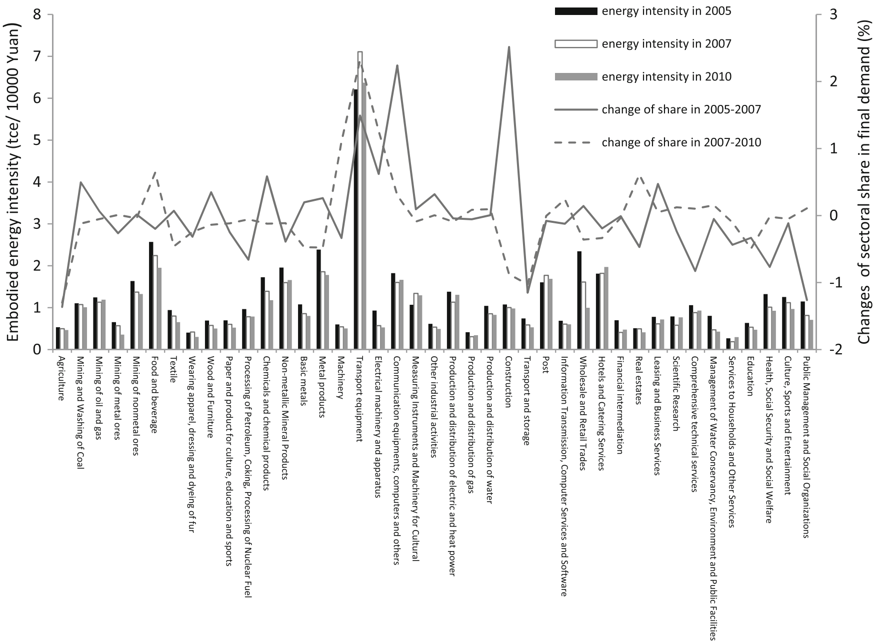

Fig. 4.1 The sectoral energy intensity and changes in sectoral share in final demand in the 11th Five-Year period. *Source* Authors' calculation

consumption in the sub-period, 2005–07, because the weighted average energy multiplier of sectors, whose shares in China's final demand decreased in the whole period and 2005–07, was lower than that of the other sectors (Fig. 4.1).

4.3 Potential Effect of EEI on ESER

The EEI is expected to be a long-term energy and economic development strategy for China. What then are the effects of this strategy on ESER in China? In this section, we evaluate the potential effect of EEI with an economy-energy-environment model for China (CN3EM).

4.3.1 Economy-Energy-Environment Model for China (CN3EM)

CN3EM is a dynamic CGE model, which consists of nine modules. Figure 4.2 depicts the production and selling structure of the model. The key behaviour equations in CN3EM are as follows.

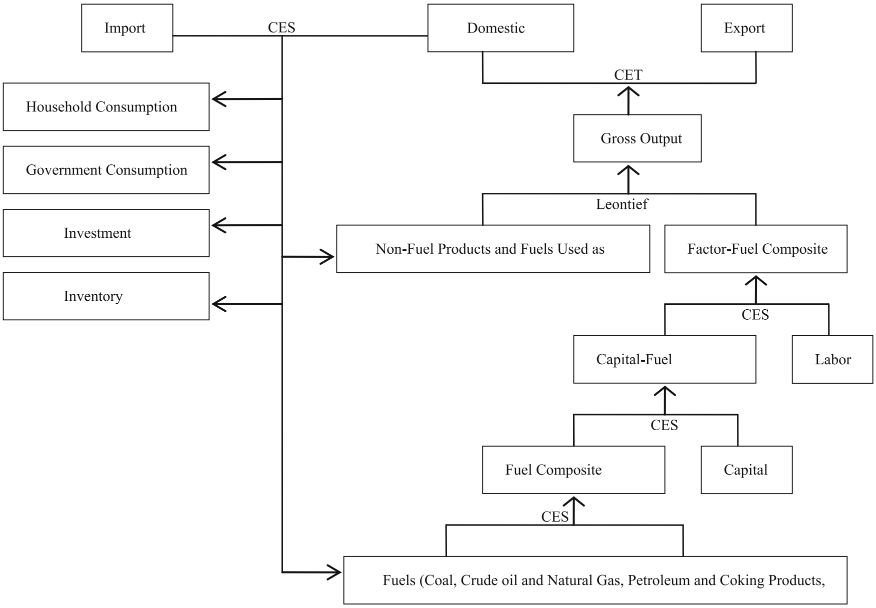

Fig. 4.2 Supply and demand of products and factors. *Source* Authors' description

4.3.1.1 Production

The production functions in CN3EM are

$$X_i = \min\left(A_{Zji}Z_{ji}, A_{Qi}Q_i\right) \tag{4.4}$$

$$Q_i = \left[\alpha_{Li}(A_{Li}L_i)^{(\sigma Qi-1)/\sigma Qi} + (1-\alpha_{Li})(A_{Ni}N_i)^{(\sigma Qi-1)/\sigma Qi}\right]^{\sigma Qi/(\sigma Qi-1)} \tag{4.5}$$

$$N_i = \left[\alpha_{Ki}(A_{Ki}K_i)^{(\sigma Ni-1)/\sigma Ni} + (1-\alpha_{Ki})(A_{Fi}F_i)^{(\sigma Ni-1)/\sigma Ni}\right]^{\sigma Ni/(\sigma Ni-1)} \tag{4.6}$$

$$F_i = \left\{\sum\nolimits_j \left[\alpha_{Zbki}(A_{Zbki}Z_{bki})^{(\sigma Fi-1)/\sigma Fi}\right]\right\}^{\sigma Fi/(\sigma Fi-1)}, \tag{4.7}$$

where Z_{ji} is the jth intermediate composite input (including fossil fuels used as material). Q_i is labour-capital-energy composite; Z_{bki} is the kth end-use fossil fuel (including fossil fuels used for electricity and heat supply); N_i is capital-energy composite, L_i, K_i, and F_i are labour, capital, and energy composite, respectively; A is input efficiency, and α and σ represent the share coefficient and substitution elasticity, respectively.

4.3.1.2 Household Consumption

We assume the maximum utility of households is under budget constraints, and the utility is the Klein-Rubin function of various kinds of composited commodities.

$$\max \prod_i (Z_{Hi} - z_{Hsubi}\Psi)^{\beta luxi} \quad (4.8)$$

$$\text{s.t. } P_{ZHi}Z_{Hi} \leq (1-s)[(1-t_H)(wL^s + U_{HP}) + U_{HG} + U_{HF}] = W_H, \quad (4.9)$$

where z_{Hsubi} is the basic demand per capita of the *i*th composited commodity; Ψ is population; P_{ZHi} is price of the *i*th composited commodity for household consumption; β_{luxi} is the share coefficient of each composite commodity in total luxury consumption; L^s is total labour supply; w is wage rate; U_{HP} is household ownership income from enterprises; U_{HG} is government transfer payment; U_{HF} is net overseas remittance; s is household saving rate; t_H is income tax rate; and W_H is total household expenditure.

4.3.1.3 Investment

We assume that the sector investment is decided by sector capital stock K_i and static expected relative rate of return Z_{Vi}. Following Jung/Thorbecke (2003), we express the sector investment equation as

$$Z_{Vi} = \alpha_{Vi}(R_i/\Omega)^{\delta i}K_i, \quad (4.10)$$

where R_i is the net rate of return of sector *i;* Ω is the interest rate; R_i/Ω is the static expected relative rate of return of sector *i*; α_{Vi} is scale coefficient of investment; and δ_i is investment elasticity. We assume that the investments of public sectors are proportional to their capital stock, $Z_{Vi} = \alpha_{Vi}K_i$. Further, similar to most of the literature, we assume that the share of investment goods Z_{Vji} is fixed in the sector investment, and that the sector inventory is proportional to sector output.

4.3.1.4 Government

The government obtains its revenue by means of levying various types of taxes and spends its revenue on purchasing commodities and subsidizing household and enterprises. Further, we assume the government levies carbon tax on fossil fuels. Let P_{Zbki0} be the price of fossil fuel without carbon tax, δ_i be the carbon coefficient of fossil fuel, and T_c be the specific carbon tax rate. Therefore, the price of fossil fuel with carbon tax is

$$P_{Zbki} = P_{Zbki0} + \delta_i T_c. \tag{4.11}$$

4.3.1.5 Trade

Following Armington (1969), we assume Armington substitution between domestic and imported goods. The demand of the *i*th imported commodity M_i can be expressed as

$$M_i = (1 - \alpha_{Di})^{\sigma i} (P_{Zi}/P_{Mi})^{\sigma i} Z_i \tag{4.12}$$

where Z_i is the domestic demand of the *i*th composited commodity; P_{Zi} and P_{Mi} are prices of Z_i and M_i, respectively; α_{Di} is the share coefficient; and σ_i ($\sigma_i > 0$) is the Armington substitution elasticity. The import price P_{Mi} is decided by the international market.

Further, we assume prices of export commodities are determined by domestic supply and foreign demand of these commodities. The domestic supply of the *i*th exported commodity E_{Si} can be expressed as

$$E_{Si} = (1 - \alpha_{Si})^{\sigma si} (P_{Ei}/P_{Xi})^{\sigma si} X_i \tag{4.13}$$

where P_{Ei} is the export price; P_{Xi} is the composite output price; α_{Si} is share coefficient; and σ_{si} ($\sigma_{si} > 0$) is the constant elasticity of transformation (CET). The foreign demand of the *i*th export commodity E_{Di} can be simply written as a decreasing function of P_{Ei},

$$E_{Di} = \beta_i P_{Ei}^{-\theta i}, \tag{4.14}$$

where β_i is scale coefficient, θ_i ($0 < \theta_i < \infty$) is the price elasticity of export.

4.3.1.6 Energy Consumption and Carbon Emissions

According to first-order condition of Eqs. (4.7) and (4.8), we can obtain the sector demand on the energy composite F_i and the *k*th fossil fuel Z_{bki}.

$$F_i = (1 - \alpha_{Ki})^{\sigma Ni} (P_{Fi}/P_{Ni})^{\sigma Ni} N_i \tag{4.15}$$

$$Z_{bki} = \alpha_{Zbki}^{\sigma Fi} (P_{Zbki}/P_{Fi})^{\sigma Fi} F_i \tag{4.16}$$

where P_{Fi} and P_{Ni} are the prices of energy composite and capital-energy composite, respectively.

4.3.1.7 Equilibrium Conditions

We assume all producers obtain zero net profit, demand equals supply for all commodities and factors, and income (or revenue) and expenditure are balanced for households and governments, international balance of payment, and investment-saving balance.

4.3.1.8 Macro Closure

We assume that the government expenditure is proportional to household expenditure, and the government transfer payment and tax rate are exogenous variables, which imply that government savings and deficits are endogenous variables. Household savings and exchange rates are fixed, whereas net foreign capital inflow is an endogenous variable, which can be adjusted to ensure the investment-saving balance.

4.3.1.9 Dynamic

We achieve the recursive dynamic in the model through factor accumulation and technology progress. Let K_i^* be the sector capital stock at period t, K_i be the sector capital stock at period 0, and Z_{Vi} be the sector investment, then we can assume that

$$K_i^* = K_i(1 - d_i) + Z_{Vi} \tag{4.17}$$

where d_i is the depreciating rate.

4.3.2 Data Preparation and Scenarios Designation

4.3.2.1 Data

We selected 2007 as the base year for the simulation. We compiled the social account matrix based on the 42-sector input-output table for 2007 from the NBSC. According to the definition of substitution elasticity and using the 2007 and 2010 comparable input-output tables, we initially estimated the Armington substitution elasticities between domestic and imported products (as shown in Table 4.2). The substitution elasticities between factors and fuels were obtained from Zhang (2013). The fuels were classified into coal, crude oil, natural gas, petroleum, coking products, coal gas, electricity, and heat.

Table 4.2 Important substitution

Fuel substitution	Capital-fuel substitution	Labour-(Capital-fuel) substitution	Armington substitution			
			Agriculture	Industry	Construction	Service
0.820	0.926	1.588	16.12	3.63	0.25	2.27

Source Authors' calculation

Table 4.3 Some assumptions underlying the forecasting scenario

	Annual change (%)
Real GDP	7.6 (2013–15), 7.0 (2016–20), 6.0 (2021–30)
Labour supply[a]	0.14 (2013–15), −0.53 (2016–20), −0.68 (2021–30)
World price of oil[b]	1.1
World price of natural gas[c]	2.0
World price of coal[c]	3.7
World price of other imports	0.0
Autonomous energy efficiency improvement (AEEI)[d]	2.5

Source Authors' calculation
Notes
[a]Various issues of *China Statistical Yearbook* and Qi (2010)
[b]According to the forecasting of EIA (2013)
[c]World Bank (http://go.worldbank.org/5AT3JHWYU0)
[d]Dai et al. (2011)

4.3.2.2 Simulation Strategy

According to Dixon/Rimmer (2002), the CGE model can be used for four types of simulation, namely, historical, decomposition, forecast, and policy simulations. We used 2008 to 2012 for historical simulation and 2013 to 2030 for forecast and policy simulations.

The forecasting simulation was used to create the business as usual (BAU) scenario from 2013 to 2030. In the BAU scenario, we assumed no carbon tax, gradual decrease in the annual growth rate of the GDP,[2] and the autonomous energy efficiency improvement (AEEI) was 2.5 %. Table 4.3 shows the assumed values of other important exogenous variables. The values of the remaining exogenous variables (such as tax rates) are assumed to be the same as 2007.

In the policy simulation, we used the energy intensity constraint (EIC) as the instrument for ESER. In the 12th Five-Year Plan, China set an EEI target, namely a

[2]Similar to some other studies (Li et al. 2003; Dai et al. 2011; Lu et al. 2013), we assume exogenous movements of real GDP, in order to adopt the GDP growth rate from the experts' projection (Li et al. 2003).

decrease in the GDP-based energy intensity of 16 % from 2010 to 2015. However, China has no official EEI target for the long term. We set two policy scenarios for 2016 to 2030. In the first policy scenario (P1), we assumed the decreasing rate of energy intensity as 3 % from 2016 to 2020, which was the same as that in the 12th Five Year period, and the rate from 2021 to 2030 was 2.5 %, which was slightly lower than the previous period (2016–2020). In the second policy scenario (P2), we assumed China could achieve the EEI target set by the Research Group of the Energy Development Strategy of China in the mid- and long-terms (2011), which suggested that the energy intensities in 2020 and 2030 are 44 and 68 % lower than that in 2005, respectively.

4.3.3 Simulation Results

4.3.3.1 Macro-effect of EEI

In the BAU scenario, energy consumption and carbon emissions grow slower than GDP because we assumed a positive AEEI value, as shown by Table 4.4. As a result, the energy and carbon intensity from 2008 to 2012 gradually but steadily decreased. Coal consumption grows slower than the total energy consumption, whereas consumption of other fuels grows faster than the total energy consumption.

Compared to the BAU scenario, all the growth rates of GDP, energy consumption, and carbon emissions decreased in the policy scenarios. Further, the

Table 4.4 Some results from forecasting and policy simulations (%)

	2013–15			2016–20			2021–30		
	BAU	P1	P2	BAU	P1	P2	BAU	P1	P2
GDP	7.63	7.61	7.61	7.04	7.00	6.98	6.06	5.99	5.82
Total carbon emissions	7.18	3.05	3.05	6.74	3.41	2.47	5.84	3.02	−0.56
Total energy consumption	7.42	3.48	3.48	6.97	3.79	2.91	6.03	3.34	0.06
Coal	6.46	1.32	1.32	6.02	1.77	0.54	5.19	1.36	−3.63
Crude oil and natural gas	8.91	8.11	8.11	8.30	7.34	7.05	6.98	5.66	3.45
Petroleum and coking products	8.47	7.64	7.64	7.92	7.00	6.72	6.73	5.62	3.65
Coal gas	10.13	3.90	3.90	9.38	3.85	2.60	7.86	3.34	−0.20
Electricity and heat	8.41	8.16	8.16	7.82	7.58	7.50	6.73	6.48	6.06
Carbon intensity	−0.43	−4.23	−4.23	−0.28	−3.35	−4.21	−0.21	−2.81	−6.03
Energy intensity	−0.20	−3.84	−3.84	−0.07	−3.00	−3.81	−0.03	−2.50	−5.44

Source Authors' calculation

decreases in energy consumption and carbon emissions are significantly larger than that of the GDP. If capital and labour are fixed, the marginal output of energy input will decrease progressively. Thus, the decreases in energy consumption and related carbon emissions should far exceed the decrease in GDP when we impose an EIC. This finding is similar to Zhang (2013), who reports that the impact of carbon intensity constraint on GDP is smaller than that of energy consumption and carbon emissions. According to our results, the annual total abatement cost of carbon emissions only accounts for about 0.002–0.2 % of the annual GDP in the baseline scenario from 2013 to 2030. As a result, the energy and carbon intensities decrease significantly compared to the BAU scenario.

Carbon intensity decreases faster in the policy scenarios than in the BAU scenario because the gap between the growth rates of carbon emissions and GDP is enlarged. Consumption of all types of fuels, especially coal and coal gas, also increases significantly more slowly in the policy scenarios compared to the BAU scenario. Although the total energy consumption will rise slowly, coal and coal gas consumption as well as carbon emissions will fall from 2021 to 2030 in P2.

In addition, EIC will cause marginal abatement costs of carbon emissions (MACCE), as shown in Fig. 4.3. The annual MACCE are 11.3 yuan per ton of carbon equivalent (Y/tc) and 30.7 Y/tc in P1 and P2 scenarios, respectively.

4.3.3.2 Sector Effect of EEI

We use P1 as an example to analyse the sector effect of EEI from 2013 to 2020, as shown in Table 4.5. The EIC causes the decrease in most of the sector outputs. From the perspective of comparative change, the decreases in outputs of sectors (such as coal mining) supplying fossil fuel are significantly larger than other sectors because the EIC reduces the demand for fossil fuel significantly. EIC also significantly reduces the outputs of most heavy industry sectors, such as metal mining, electricity and heat supply, and metal smelting and rolling. At the same time, EIC

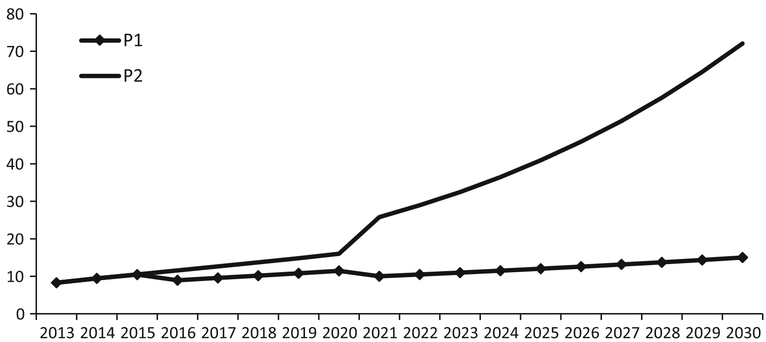

Fig. 4.3 Marginal abatement cost of carbon emissions in policy scenarios. *Source* Authors' calculation

Table 4.5 Sector impact of EEI in P1 scenario in 2013–30 (compared to the BAU scenario)

Sector	Output		Fossil fuels		Carbon emissions	
	10^8 Y	%	10^4 tce	%	10^4 tc	%
Agriculture	−6126	−0.3	−936	−19.7	−909	−30.1
Coal Mining	−85,756	−20.4	−1028	−37.8	−727	−52.4
Petroleum and Gas Extraction	−26,865	−4.6	−123	−11.6	−199	−31.0
Metal Mining	−12,378	−2.7	−13	−5.6	−14	-8.8
Non-metal Mining	−4352	−1.8	−15	−6.1	−47	−28.4
Foods and Tobacco	−5009	−0.3	−121	−12.5	−146	−22.1
Textile	4264	0.5	−49	−10.5	−52	−15.9
Wearing Apparel and Related Articles	1275	0.2	−6	−4.8	−6	−7.1
Furniture	−6605	−1.2	−13	−7.7	−12	−10.0
Paper and Related Articles	−5033	−0.6	−105	−14.7	−105	−20.8
Petroleum and Nuclear Fuel and Coking	−57,795	−5.5	−219	−7.7	−372	−22.1
Chemical	−46,882	−1.2	−257	−3.6	−66	−4.2
Non-metallic Mineral Products	−28,256	−2.0	−729	−10.9	−628	−14.3
Metals Smelting and Rolling	−86,598	−2.3	−1997	−12.4	−1642	−14.6
Metal Products	−19,680	−1.9	−17	−6.9	−13	−8.1
Basic Machinery	−52,533	−2.2	−83	−8.8	−63	−9.6
Transport Equipment	−34,805	−1.7	−57	−10.1	−60	−16.1
Electrical Equipment	−24,438	−1.4	−12	−6.6	−11	−9.6
Electronic Equipment	10,932	0.5	−9	−5.2	−11	−10.0
Measuring Instrument and Office Machinery	6	0.0	−1	−5.0	−1	−5.1
Artwork and Other Manufacture	−3005	−1.0	−10	−7.4	−9	−10.4
Scrap and Waste	−4192	−1.6	0	−5.2	0	−5.3
Electricity and Heat Supplying	−47,810	−2.5	−7730	−18.6	−12079	−39.0
Coal Gas Supplying	−12,356	−15.4	−23	−15.4	−277	−65.1
Water Supplying	−1026	−1.5	−1	−6.7	−3	−19.5
Construction	−75,539	−2.0	−148	−7.3	−97	−8.3
Transport and Storage	−29,867	−1.5	−461	−6.2	−285	−6.5
Post	−303	−0.7	−6	−8.4	−4	−9.0
Information and Computer Services	−4725	−0.6	−2	−8.9	−2	−10.0
Trades	−5701	−0.3	−90	−14.3	−73	−19.1
Hotels and Catering	−5739	−0.7	−26	−7.5	−209	−15.0
Financial Intermediation	−10,291	−0.9	−6	−5.7	−3	−5.9
Real Estate	−1117	−0.1	−5	−5.2	−3	−5.4
Leasing and Business	−754	−0.1	−14	−4.8	−9	−5.4
Research and Development	−768	−1.0	−1	−6.4	−1	−7.2
Comprehensive Technical Services	−4150	−1.6	−7	−6.7	−4	−7.0

(continued)

Table 4.5 (continued)

Sector	Output		Fossil fuels		Carbon emissions	
	10^8 Y	%	10^4 tce	%	10^4 tc	%
Management of Water, Environment and Public Facilities	−744	−0.6	−5	−5.5	−3	−6.2
Households and Other Services	−4023	−0.8	−11	−5.9	−8	−6.6
Education	−2217	−0.3	−24	−6.3	−17	−7.4
Health and Social Security and Welfare	−2865	−0.5	−13	−7.0	−9	−8.0
Culture, Sports and Entertainment	−1073	−0.6	−3	−6.0	−2	−7.5
Public Management and Social Organization	−3269	−0.4	−48	−6.1	−30	−6.6

Source Authors' calculation
Note 'tce' is the abbreviation of "ton of coal equivalent"

has a relatively small effect on agriculture, most of the light industry, and service sectors.

Fossil fuel consumption (FFC) in each sector decreases under the EIC. From the perspective of absolute change, the largest reduction in the FFC of occurs in electricity and heat supply, which is also the sector with the largest FFC. The sector with the second largest reduction in FFC is metal smelting and rolling, which is a major FFC sector. These two sectors account for 67 % of the total reduction in FFC. In addition, reductions in FFC of coal mining, agriculture, and non-metallic mineral products are also conspicuous, which account for 19 % of the total reduction in FFC.

Given that carbon emissions are caused by FFC, the largest reductions in carbon emissions belong to the sectors with the largest reductions in FFC. Among those sectors, electricity and heat supply contributes 66 % to the total carbon emissions reduction. Metal smelting and rolling contribute 9 % and coal mining, agriculture, and non-metallic mineral products contribute 12 % to the total carbon emissions reduction. The subtotal contribution of the rest of the 37 sectors is not more than 13 %.

Further, our detailed results show that in the baseline scenario, where we assume AEEI in each sector, the sector energy consumption and carbon emissions will increase even faster than the sector outputs in some sectors, such as the agriculture sector, because of the rebound effect of AEEI. On one hand, the above findings indicate that the extreme case of rebound effect, 'backfire' (Turner 2009), will occur in the above sectors. According to Anson/Turner (2009), Hanley et al. (2009), Turner (2009), and Turner/Hanley (2011), the backfire case implies that the general equilibrium price elasticities of demand for energy are very high (higher than one) in these sectors. On the other hand, the results also indicate that the marginal products of energy are relatively small in these sectors and the changes in energy consumption will take very small effects on the changes in outputs in these sectors.

4.3.3.3 Sensitivity Analysis

The EIC effects partly depend on the value of factor-energy substitution elasticity. To analyse the sensitivity of EIC effects, we employ two simulations by reducing and increasing 20 % of the factor-energy substitution elasticity. Table 4.6 shows that the EIC effects are quite sensitive to the value of factor-energy substitution elasticity. As the effects are large, the elasticity is also large. The results imply that we should pay attention to the uncertainty from factor-energy substitution elasticity to explain EIC effects.

At the same time, we conducted two experiments to observe the sensitivity of EIC effects to AEEI. In the first experiment, we assumed no AEEI. Regardless of the EIC effects on the economy, energy consumption and carbon emissions are larger compared to the original simulation scheme. In the second experiment, we enlarged the AEEI, which resulted in the EIC effects slightly decreasing compared to the original simulation scheme.

It seems that enlarging AEEI will decrease EIC effects on energy consumption and carbon emissions as well as energy and carbon intensity. This finding can be explained as follows. In the baseline scenario (forecasting scenario), larger AEEI will decrease energy consumption and carbon emissions as well as energy and carbon intensity in the studied period. In the police scenario, changing AEEI will take no effect on energy and carbon intensity because the energy intensity is fixed. At the same time, enlarging AEEI will take almost no effect on energy consumption and carbon emissions in the policy scenario because it has a very small effect on GDP and the energy intensity is fixed. Therefore, enlarging AEEI will reduce the gap between energy and carbon intensity as well as the gap between energy

Table 4.6 Impact of EIC under different factor-energy substitution elasticity in 2013–30 (percentage change compared to the BAU scenario)

	All elasticity reduced by 20 %		Original elasticity		All elasticity increased by 20 %	
	P1	P2	P1	P2	P1	P2
GDP	−0.17	−0.60	−0.47	−1.09	−0.77	−1.49
Total carbon emissions	−21.87	−32.67	−29.04	−39.02	−34.27	−43.60
Total energy consumption	−21.36	−31.69	−28.01	−37.55	−32.86	−41.79
Coal	−26.07	−38.54	−35.32	−46.61	−41.94	−52.27
Crude oil and natural gas	−6.60	−13.30	−10.07	−17.23	−12.66	−20.00
Petroleum and coking products	−6.24	−12.48	−9.35	−15.94	−11.64	−18.39
Coal gas	−37.99	−48.98	−42.65	−51.68	−45.66	−53.72
Electricity and heat	−1.73	−3.40	−2.55	−4.26	−3.15	−4.84
Carbon intensity	−19.03	−27.27	−25.23	−32.91	−29.81	−37.06
Energy intensity	−18.58	−26.46	−24.34	−31.66	−28.58	−35.49

Source Authors' calculation

Table 4.7 Impact of EIC under different AEEI in 2013–30 (percentage change compared to the BAU scenario)

	AEEI = 0		AEEI = 2.5 (original value)		AEEI = 4	
	P1	P2	P1	P2	P1	P2
GDP	−0.56	−1.23	−0.47	−1.09	−0.42	−1.00
Total carbon emissions	−30.92	−40.70	−29.04	−39.02	−27.89	−37.99
Total energy consumption	−29.57	−38.92	−28.01	−37.55	−27.06	−36.71
Coal	−37.85	−48.80	−35.32	−46.61	−33.71	−45.22
Crude oil and natural gas	−10.92	−18.06	−10.07	−17.23	−9.52	−16.65
Petroleum and coking products	−10.09	−16.65	−9.35	−15.94	−8.86	−15.44
Coal gas	−41.03	−49.74	−42.65	−51.68	−43.40	−52.65
Electricity and heat	−2.88	−4.66	−2.55	−4.26	−2.35	−4.01
Carbon intensity	−26.85	−34.40	−25.23	−32.91	−24.25	−32.00
Energy intensity	−25.68	−32.87	−24.34	−31.66	−23.52	−30.93

Source Authors' calculation

consumption and carbon emissions in the baseline scenario and that in the policy scenario (Table 4.7).

4.4 Discussion: Opportunities and Challenges of EEI in China

Our analysis shows that EEI is a very important approach for ESER in China. However, achieving the EEI target is not easy for China. The EEI had a significant effect on ESER in China in the 11th Five-Year period, in which the heavy and chemical industries entered a new expansion stage. However, the energy consumption and carbon emissions continued to increase significantly in the same period because of other factors, such as the increase in total final demand. Further, the EEI effects from 2007 to 2010 were significantly smaller than those from 2005 to 2007. This finding implies that EEI and its effect on ESER will be smaller, or China will need to pay more to achieve its EEI targets. Therefore, EEI in China has numerous uncertainties.

On the one hand, the adjustment in the development strategy of China provides a series of opportunities for the EEI. First, the 18th National Congress of the Communist Party of China (CPC) enhances the position of ecological progress to as high as economic, political, cultural, and social progress. This observation suggests that ecological progress should be incorporated into all aspects and the entire process of advancing the other four progresses. The congress emphasises revolutionary energy production and consumption, controlling total energy consumption, enforcing energy conservation, and supporting the development of energy-saving and low carbon industries, and new and renewable energies. To guide the further development of China, these requirements are helpful in stimulating local governments and government departments to exert efforts to improve EE.

Second, our analysis shows that industrial sectors, especially the heavy industrial sectors (such as electricity and heat supply), are either the major energy consumption or the major energy-saving sectors. The industrial development of China at present still lags behind other industrial countries. Nevertheless, China has a late-development advantage, namely, adopting advanced technologies to equip the entire industrial sector to facilitate rapid progress in EE. For example, the EE in the electricity and heat supply can be significantly improved by raising the ratio of co-generation of heat and power, safely and effectively accelerating electricity net development to realise intra-regional electricity allocation, and replacing low-efficiency power plants with high-efficiency plants. At the same time, the government could improve the EE of industrial sectors by enforcing management, such as the closing of low-efficiency energy-intensive plants. Aside from the industrial sectors, the government can improve EE in other areas by actively promoting the application of energy conservation technologies and equipment.

Third, the Chinese government could impose more effective policies to promote EEI. The government should invest more in energy conservation. For example, the State Council of China (2013) stated that the government will provide financial support (including subsidy, rewards, and subsidised interest); will assume the lead role in energy conservation technology reconstruction; will encourage enterprises to invest in energy conservation, such as supporting enterprises in efforts to be responsible for the national energy conservation technology project; and will develop a batch of demonstration centres of energy conservation. Aside from increasing investment, the government will also guide energy-saving production patterns and lifestyles by means of increasing the ratio of energy-saving products in government purchases, developing green credit for energy-saving enterprises, and energy price reform.

However, China also faces a number of challenges in EEI. First, upgrading the energy technology is not easy because of the lack of core technology. Although China has made rapid progress in energy conservation technology, capital or research and development in energy-saving service enterprises remain very weak in the country. Moreover, time is necessary to innovate the energy conservation technology, and obtaining foreign advance energy conservation technology is difficult for China. Its lack of core technology may lead to a bottleneck of EEI in the near future.

Second, domestic and foreign driving forces to upgrade China's industrial structure are still weak. The industrial sector is the major energy consumption sector in China and will assume an important role in the near future. On the one hand, the demand for industrial products is huge because China is still at the rapid industrialisation and urbanisation stages. For example, huge infrastructure and equipment upgrades will require substantial investments, which will consume massive industrial products. On the other hand, China is struggling to develop its service sectors: at the domestic level, household consumption in China is not strong enough to pull the

Table 4.8 The total energy consumption rebound effect in AEEI under different factor-energy substitution elasticity (%)

Value of elasticity	Value of AEEI (%)	2013–15	2016–20	2021–30
Original elasticity	AEEI = 2.5	92.0	97.3	98.8
All elasticity reduce by 20 %	AEEI = 2.5	59.5	65.5	70.7
All elasticity increase by 20 %	AEEI = 2.5	118.1	122.0	119.9

Source Authors' calculation

development of service sectors quickly; and at the international level, the Chinese service sectors presently lack competition from the global market.

Third, China lacks an effective supervising and stimulating mechanism to ensure that energy conservation policies will work. Although the Chinese government formulates policies for energy conservation, many only appear on paper, and can not be implemented because no related supervising and stimulation mechanisms are in place. For example, the central government requires local governments to close or suspend the operations of low-efficiency energy-intensive plants. However, many such plants continue operating because some local governments do not want to deal with related financial and employment problems.

Further, the total energy consumption rebound effect of EEI is also an important challenge for China. Table 4.8 shows the rebound effect of AEEI estimated by taking the method proposed by Anson/Turner (2009), Hanley et al. (2009), Turner (2009), and Turner/Hanley (2011). The results indicate that the rebound effect of AEEI is rather high and it will increase as time passes. This finding is similar to the results reported by Anson/Turner (2009), who find that the total oil rebound effect of EEI in the Scottish commercial transport sector in the long run is higher than that in the short run. In addition, the rebound effect of EEI is also sensitive to the value of factor-energy substitution elasticity.

4.5 Conclusion

By using the input-output SDA and a dynamic economy-energy-environment CGE model for China, we evaluated the effects of energy intensity reduction on energy consumption and related carbon emissions in China. Our major findings are as follows.

Energy intensity reduction is very helpful in reducing energy consumption and carbon emissions in China in the 11th Five-Year period, but energy consumption and carbon emissions continue to increase significantly during the same period because of rapid economic growth and activity.

Reducing energy intensity will continuously result in large reductions in energy consumption and carbon emissions in the future, and its effects can only offset part of the large-scale effects of economic activity. Hence, China will need to implement a very ambitious plan to reduce energy intensity.

Although energy consumption and carbon emissions substantially decreased because of the energy intensity reduction, the fall in GDP is negligible. This finding implies that energy intensity reduction is consistent with the development strategy of China, such as quickly developing the economy and ensuring resource and environment security at the same time.

Under energy intensity constraint, coal and coal gas consumption decreased more quickly than oil and gas consumption. At the same time, electricity and heat consumption decreased more slowly than fossil fuel consumption, which indicates that energy intensity reduction optimises the fuel mix in China.

The industrial structure will also be optimised by energy intensity reduction in China. The outputs of sectors supplying fossil fuel and energy-intensive sectors decreased significantly, whereas outputs in the light industrial and service sectors decreased by only a small amount.

The rate of decrease in the sectors' energy consumption and carbon emissions depends on energy intensity reduction. Electricity and heat supply is the most important sector in reducing energy consumption and carbon emissions in China because most of the energy consumption and carbon emissions are contributed by this sector. Other important sectors include metal smelting and rolling, coal mining, agriculture, and non-metallic mineral products.

Finally, China needs to implement a series of policies, such as a carbon tax, to support EE improvement. The Chinese government has many plans to improve EE, but many challenges stand in the way of the implementation of them. China should take a more active role to overcome these obstacles and achieve the EE target.

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Chapter 5
Energy and Pollution Efficiencies in China's Regions

Jin-Li Hu and Tzu-Pu Chang

Abstract Along with rapid economic growth over the past decades, China is now facing a dual challenge of improving both energy and emission efficiencies. To trace the trends of energy and pollution efficiencies, this chapter proposes two indices: ecological total-factor energy efficiency (ETFEE), and ecological total-factor pollution efficiency (ETFPE) based on the Russell-based directional distance function. Using regional data from 2001 to 2011, the result shows that the ETFPE is always lower than the ETFEE for any area in China in the same year, indicating that the country is facing a more serious situation with respect to pollution control compared to energy saving.

Keywords China · Ecological total-factor energy efficiency · Ecological total-factor factor pollution efficiency · Russell-based directional distance function

5.1 Introduction

Since the economic reforms in 1978, China's per capita GDP has been growing at an average rate of more than 8 % a year, and China has become the world's second largest country in terms of GDP (Zhu 2012). With rapid economic growth, however, China is facing a dual challenge of improving both energy and emission efficiencies. For example, in addition to the rising energy consumption, the Asian Brown Cloud problem is becoming more and more serious in north China, and also affects the neighbouring countries in Northeast Asia (Hu et al. 2005).

More specifically, with respect to energy consumption, China in 2010 became the world's biggest energy consumer with a whopping 20.3 % share of global energy use (BP 2011). However, some researchers argue that the imbalance in

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supply and demand for energy will be a critical problem in the coming years (Liu 2011; Li/Hu 2012). For example, China's energy consumption structure relies heavily on coal. Nevertheless, if coal demand continues to grow in line with economic growth, the reserves lifetime of coal would be only 19 years (Wang/Hao 2012). In addition, coal imports have increased quickly in the past decade, and national energy security may become a threat in the long term.

The second challenge China faces is the unhealthy growth model, called "high growth, high pollution", especially with respect to air pollution emissions. Over the past three decades, the increasing numbers of heavy industries, power plants, factories and vehicles have been sources of major pollutants and have had negative impacts on people's health and the environment. For instance, 7 of the 500 largest cities in China are ranked among the 10 most polluted cities in the world (Asian Development Bank 2013; Li/Zhang 2014). The unfavourable effects of exposure to air pollution have also impacted daily mortality (Chang/Yao 2008; Meng et al. 2013). Moreover, the economic loss caused by pollution has reached 1.4 trillion RMB, which accounted for 3.9 % of GDP in 2008. If no further action is taken to control air pollution, Xing et al. (2011) predict that emissions of SO_2 and NOx will grow by 17 and 50 %, respectively in 2020, based on trends in 2005. According to these studies, it is suggested that air pollution in China will continue to be a problem in the future.

In 2013, only 3 out of the 74 cities monitored by the central government met the minimum air quality standards. Beijing, with 20 million people, met the minimum air quality standards up to 40 % for all days in 2013 (Wong 2014). Moreover, among these 74 monitored cities, Hebei province ranked 7 out of the top 10 cities with the highest PM 2.5 air pollution levels. Tianjin and Beijing were close runners up at 11th and 13th place, respectively (Greenpeace East Asia 2014).

Improving both energy and emission efficiencies is one of the best ways to prevent the aforementioned energy and pollution problems. This chapter constructs an innovative indicator to monitor both energy and emission efficiencies over time and across regions in China. Catching the relationships among inputs and outputs, the data envelopment analysis (DEA) is a widely used method to compute energy and environmental efficiency (Zhou et al. 2008). Specifically, this study uses a directional distance function model with undesirable outputs to calculate the technical efficiency of a production system in which desirable and undesirable outputs are jointly produced. Hence, the targets of inputs and undesirable outputs can be obtained simultaneously. We then extend the total-factor energy efficiency (TFEE) defined by Hu/Wang (2006) and the total-factor pollution efficiency (TFPE) defined by Hu (2006) by taking into account the pollution, e.g. caused by SO_2 emissions, in order to find the energy and emission efficiencies of Chinese regions.

Two indices are proposed in this study. The ecological total-factor energy efficiency (ETFEE) is defined as "the target energy input/the actual energy input" while the ecological total-factor factor pollution efficiency (ETFPE) is defined as "the target pollution/the actual pollution", which are both fitting the standard efficiency definition to be between zero and one. Many existing articles have separately analysed the overall environmental efficiency or total-factor energy efficiency with undesirable outputs in China (e.g. Li/Hu 2012; Wang et al. 2012). More recently, some papers investigate China's energy and pollution efficiency simultaneously. For instance, Wang et al. (2013a) use a range-adjusted measure DEA to evaluate China's regional energy and emissions efficiency under natural and managerial disposability assumptions. Wang et al. (2013b) apply a multi-directional efficiency analysis approach to measure Chinese regional energy and emissions efficiency. They find that the east area has the highest energy and emissions efficiency compared to the west and central areas. Wang/Wei (2014) investigate both energy utilisation and CO_2 emissions efficiency for the industrial sector of 30 major Chinese cities.

As mentioned above, both energy and pollution efficiencies are very important issues for China at present. Therefore, this analysis applies a new approach—the Russell-based directional distance function model to investigate China's regional energy and emissions efficiency. By using an innovative model, this analysis tries to provide some fresh insights for the government and policymakers.

The remainder of this chapter is organised as follows. The next section introduces the methodology and proposed indices. Then the collected data and empirical results are described. This is followed by the conclusions.

5.2 Methodology

5.2.1 Environmental DEA Technology

Traditional DEA models assume that inputs can produce outputs, and all inputs and outputs can be freely adjusted, i.e. inputs minimisation or outputs maximisation. However, undesirable outputs (such as pollutant emissions) do not fit the assumption of outputs maximisation and the reduction of undesirable outputs should be costly. Earlier literature therefore treats undesirable outputs as inputs or use data translation in order to minimise undesirable outputs in traditional DEA models.

Färe et al. (1989) relax the strong disposability property in traditional DEA models and assume a weak disposability of undesirable outputs to treat desirable and undesirable outputs differently. Färe et al. (1996) formally introduce an environmental production technology considering desirable and undesirable outputs simultaneously. Since the work of Färe et al. (1996), the environmental production technology has been widely accepted to evaluate environmental performance with undesirable outputs (e.g. Chung et al. 1997; Färe/Grosskopf 2004; Färe et al. 2004; Zhou et al. 2008). We briefly illustrate the environmental production technology as follows.

Assume that $X \in R_+^M$, $Y^g \in R_+^N$, and $Y^b \in R_+^J$ are the vectors of inputs, desirable outputs, and undesirable outputs, respectively. The production technology can be generally described as:

$$T = \{(X, Y^g, Y^b) : X \text{ can produce} (Y^g, Y^b)\}. \tag{5.1}$$

In order to reasonably model a production process in which both desirable and undesirable outputs are jointly produced, Färe et al. (1996) proposed two assumptions on the environmental production technology. The first is that outputs are weakly disposable; i.e. if $(X, Y^g, Y^b) \in T$ and $0 \le \theta \le 1$, then $(X, \theta Y^g, \theta Y^b) \in T$. The second is that desirable and undesirable outputs are null-joint; i.e. if $(X, Y^g, Y^b) \in T$ and $Y^b = 0$, then $Y^g = 0$. The first assumption implies that the reduction of undesirable outputs is not free, and the proportional reduction in desirable and undesirable outputs at the same time is feasible. This second assumption implies that some undesirable outputs must also be produced when desirable outputs are produced.

With respect to the DEA framework, T can be described by the linear combination of the data. Suppose there are K DMUs in the data set. Each DMU uses inputs $X = (x_{1k}, x_{2k}, \ldots, x_{Mk}) \in R_+^M$ (k = 1, …, K) to jointly produce desirable outputs $Y^g = (y_{1k}^g, y_{2k}^g, \ldots, y_{Nk}^g) \in R_+^N$ and undesirable output $Y^b = (y_{1k}^b, y_{2k}^b, \ldots, y_{Jk}^b) \in R_+^J$. The environmental DEA technology can be expressed as follows:

$$\begin{aligned} T = \{(X, Y^g, Y^b) : & \sum_{k=1}^{K} \lambda_k x_{mk} \le x_m, \quad m = 1, 2, \ldots, M \\ & \sum_{k=1}^{K} \lambda_k y_{nk}^g \ge y_n^g, \quad n = 1, 2, \ldots, N \\ & \sum_{k=1}^{K} \lambda_k y_{jk}^b = y_j^b, \quad j = 1, 2, \ldots, J \\ & \lambda_k \ge 0, k = 1, 2, \ldots K\}. \end{aligned} \tag{5.2}$$

where λ_k is intensity variables representing the weight of each DMU. Equation (5.2) satisfies all the above-mentioned assumptions: The inequalities of the input and desirable output imply that the input and desirable output are strongly disposable. With the equality of undesirable output considered, the desirable and undesirable outputs are weakly disposable. In addition, Eq. (5.2) imposes that $Y^b > 0$ which fit the assumption of null-jointness. Notice that the above definition corresponds to the constant returns to scale technology.

5.2.2 Efficiency Measure: Russell-Based Directional Distance Function

Färe et al. (1996) first introduced the issue of environmental production technology and used the Shephard input distance function to evaluate DMUs' environmental efficiency. Sequentially, Färe/Grosskopf (2004) applied a more general approach—the directional distance function (DDF) introduced by Chung et al. (1997) to solve the efficiency model. Recently, Färe/Grosskopf (2010) have proposed a generalised DDF approach that is more flexible than the original DDF model (Chang/Hu 2010). They also show that the slack-based DEA model is a special case of the generalised DDF approach.

Aside from the aforementioned literature, this analysis adopts a Russell-based directional distance function (RDDF, hereafter) approach to investigate China's energy and pollution efficiency. In fact, the RDDF model is a closely related measure of the generalised DDF approach. The only difference between the two models is the objective function in the linear programming problem. Chen et al. (2015) prove that the RDDF model presents some well-behaved properties and has a higher discriminating power than the Farrell efficiency measure.

Theoretically, the DDF model allows us to expand desirable outputs and contract inputs as well as undesirable outputs simultaneously. Following Chung et al. (1997), the DDF could be defined as:

$$\overrightarrow{D}(X, Y^g, Y^b; g_X, g_{Y^g}, g_{Y^b}) = \max\{\beta : (X - \beta g_X, Y^g + \beta g_{Y^g}, Y^b - \beta g_{Y^b}) \in T\} \tag{5.3}$$

where the nonzero vector (g_X, g_{Y^g}, g_{Y^b}) denotes the directions in which inputs, desirable and undesirable outputs are adjusted by an equal scale. It is noted that $\overrightarrow{D}(X, Y^g, Y^b; g_X, g_{Y^g}, g_{Y^b}) \geq 0$ and $\overrightarrow{D}(X, Y^g, Y^b; g_X, g_{Y^g}, g_{Y^b}) = 0$ if and only if (X, Y^g, Y^b) is on the production frontier. The RDDF model, however, allows all inputs and outputs to be adjusted by different scales, meaning that there is no unique direction. Letting $(g_X, g_{Y^g}, g_{Y^b}) = (X, Y^g, Y^b)$, the RDDF for the o-th DMU can be expressed as the following linear programming problem:

$$\begin{aligned}
&\vec{D}(X, Y^g, Y^b) = \max \frac{1}{M+N+J}\Big(\sum_{m=1}^{M} \beta_m^x + \sum_{n=1}^{N} \beta_n^g + \sum_{j=1}^{J} \beta_j^b\Big) \\
&\text{s.t.} \quad \sum_{k=1}^{K} \lambda_k x_{mk} \leq (1 - \beta_m^x) x_{mo}, \quad m = 1, 2, \ldots, M \\
&\sum_{k=1}^{K} \lambda_k y_{nk}^g \geq (1 + \beta_n^g) y_{no}^g, \quad n = 1, 2, \ldots, N \\
&\sum_{k=1}^{K} \lambda_k y_{jk}^b = (1 - \beta_j^b) y_{jo}^b \quad j = 1, 2, \ldots, J \\
&\lambda_k \geq 0,\ \beta_m^x \geq 0,\ \beta_n^g \geq 0, \beta_j^b \geq 0, \quad k = 1, 2, \ldots, K.
\end{aligned} \tag{5.4}$$

According to Eq. (5.4), $\overrightarrow{D}(X, Y^g, Y^b)$ denotes the inefficiency score for the o-th DMU, implying that the o-th DMU is efficient if and only if all βs are equal to zero.

Moreover, β_m^x, β_n^g and β_j^b would be the inefficiency level of each input, desirable and undesirable output, respectively.

5.2.3 The Ecological Total-Factor Energy and Pollution Efficiencies

By definition, ETFEE is a ratio of target energy input to actual energy input. Because actual energy input is always greater than or equal to target energy input, TFEE must be smaller than unity. The ETFEE score of region *i* at time *t* is defined as

$$\mathrm{ETFEE}(i,t) = \frac{\text{Target energy input}\,(i,t)}{\text{Actual energy input}\,(i,t)} \tag{5.5}$$

This definition is consistent with that in Hu/Wang (2006) by further incorporating the undesirable output (such as pollution) into the DEA model to find the target energy. Li/Hu (2012) first used this index to compute the regional energy efficiency in China. However, they did not compare the target and actual pollutions. On the other hand, we can define an ecological total-factor pollution efficiency index.

$$\mathrm{ETFPE}(i,t) = \frac{\text{Target pollution}\;(i,t)}{\text{Actual pollution}\;(i,t)} \tag{5.6}$$

It is noted that the desirable pollution target is always less than or equal to the actual pollution. Both target energy input and target pollution can be calculated by the RDDF DEA model because βs obtained from Eq. (5.4) are equivalent to the contraction proportions of inputs and undesirable outputs.

5.3 Empirical Findings

5.3.1 Data

The empirical study of this chapter uses data for 29 administrative regions in China over 2001–11. There is one desirable output (GDP), one undesirable output (SO_2), and four inputs (capital stock, labour, energy, and farmland area) in the DEA models. Note that the farmland area is a proxy for bio-mass energy sources, as in Hu/Wang (2006). The data for GDP, labour, farmland area and SO_2 emissions are from the *China Statistical Yearbook*, while energy consumption comes from the *China Energy Statistical Yearbook*. Energy consumption data contains each regions' total energy consumption (unit of ten thousands tce) including the conventional energy types—mainly coal, petroleum and natural gas. Capital stock from 2001 to 2006 is estimated by Shan (2008) and then extended to 2011 based on Shan's approach. It is noted that all variables with monetary units are transformed into 2010 prices with a GDP deflator. Table 5.1 depicts the summary of statistics for all inputs and outputs. Table 5.2 shows the correlation matrix among all used variables. It is found that all inputs positively correlate positively with two outputs. This is consistent with economic intuition and the production theory.

5.3.2 Results

Table 5.3 presents the average overall inefficiency (i.e. sum of βs), ETFEE scores, and ETFPE scores over the research period. With respect to overall inefficiency, Beijing, Tianjin, Guangdong and Shanghai are the best performers (inefficiency scores are zero), while Ningxia is the poorest region. As for ETFEE scores, Beijing,

Table 5.1 Summary of statistics of inputs and outputs for regions in China (2001–11)

Variable	Unit	Mean	S.D.	Max	Min
Outputs					
Real GDP	100 million RMB in 2010	9950.942	8912.301	50614.37	
SO_2	ton	758642.0	500,399.1	2141000.0	22000.00
Inputs					
Energy	10,000 tce	9838.889	7039.814	37132.00	520.0000
Labour	10,000 persons	2317.001	1663.017	6909.672	128.7666
Capital	100 million RMB in 2010	1154.272	1339.380	7786.520	15.16156
Farm area	1,000 ha	5368.862	3712.557	14258.61	295.0100

Source China Statistical Yearbook, China Energy Statistical Yearbook; Shan (2008); and authors' calculation

Table 5.2 Correlation coefficients among outputs and inputs

	GDP	SO_2	Energy	Labour	Capital	Farm area
GDP	1.000	0.500	0.878	0.707	0.544	0.349
SO_2	0.500	1.000	0.740	0.678	0.125	0.648
Energy	0.878	0.740	1.000	0.716	0.418	0.532
Labour	0.707	0.678	0.716	1.000	0.150	0.750
Capital	0.544	0.125	0.418	0.150	1.000	−0.073
Farm area	0.349	0.648	0.532	0.750	−0.073	1.000

Source Authors' calculation

Table 5.3 The average energy and pollution efficiency scores of regions in China (2001–11)

Region	Area	Overall inefficiency	ETFEE	ETFPE
Beijing	E	0.000	**1.000**	**1.000**
Tianjin	E	0.000	**1.000**	**1.000**
Hebei	E	0.466	0.424	0.405
Shanxi	C	0.477	0.293	0.221
Inner Mongolia	W	0.503	0.443	0.233
Liaoning	E	0.046	0.886	0.885
Jilin	C	0.388	0.541	0.521
Heilongjiang	C	0.358	0.515	0.543
Shanghai	E	0.000	**1.000**	**1.000**
Jiangsu	E	0.154	0.915	0.760
Zhejiang	E	0.065	0.924	0.889
Anhui	C	0.000	**1.000**	**1.000**
Fujian	E	0.025	0.975	0.984
Jiangxi	C	0.447	0.837	0.432
Shandong	E	0.355	0.646	0.532
Henan	C	0.433	0.622	0.417
Hubei	C	0.348	0.608	0.538
Hunan	C	0.272	0.755	0.560
Guangdong	E	0.000	**1.000**	**1.000**
Guangxi	W	0.414	0.743	0.248
Hainan	E	0.022	0.993	0.971
Sichuan	W	0.025	0.969	0.953
Guizhou	W	0.536	0.410	0.218
Yunnan	W	0.207	0.774	0.758
Shaanxi	W	0.283	0.799	0.527
Gansu	W	0.545	0.418	0.246
Qinghai	W	0.544	0.375	0.317
Ningxia	W	0.612	0.346	0.126
Xinjiang	W	0.319	0.626	0.529
Average		0.270	0.719	0.614

Source Authors' calculation

Tianjin, Guangdong, Shanghai and Anhui are efficient for energy consumption in each year. However, on average, Shanxi becomes the worst region rather than Ningxia. Five regions have an ETFPE score with unity but the average ETFPE for the whole of China is lower than the ETFPE. This pattern is similar to Wang et al. (2013b) in which energy efficiency is higher than emission efficiency, even though they evaluate CO_2 emission efficiency rather than SO_2 emissions in our analysis. One possible explanation is that the ETFPE and ETFEE are relative performance

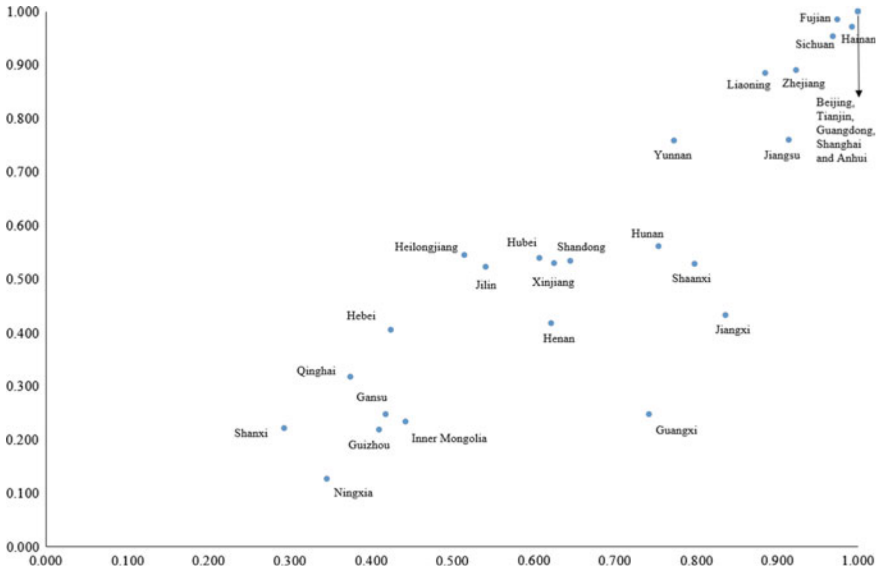
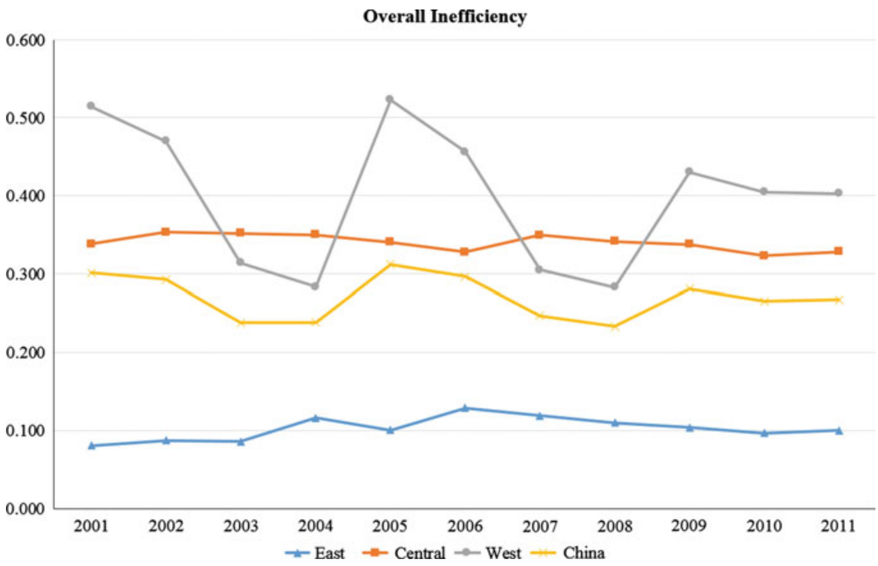


Fig. 5.1 Average ETFEE and ETFPE scores of regions in China. *Source* Table 5.3

measures. Hence, the result illustrates that the gap between efficient and inefficient regions for pollutant emissions is large, while the difference among energy usage is relative small.

In addition, Fig. 5.1 shows a scatter plot for ETFEE and ETFPE. The result presents a highly positive relationship between ETFEE and ETFPE. However, two regions, i.e. Guanxi and Jiangxi, represent a huge gap between ETFEE and ETFPE, showing that the pollution efficiency is much lower than energy efficiency.

In order to highlight the imbalanced performance among the regions, we further compare the performance according to different areas (the East, West and Central areas of China). As Fig. 5.2 shows, the empirical model shows that the overall inefficiency score rankings for three major areas are east (0.103), central (0.340) and west (0.399) from 2001–11. This ranking implies that the more advanced and richer area in China has a higher overall efficiency. Compared to the east area, the overall inefficiency scores in the central and west areas are quite high, implying that they are only about or below two-thirds of the way from the efficiency frontier of China. As a result, improving the overall technical efficiency in the central and west areas is an urgent challenge for China now. Figure 5.2 also shows that the overall inefficiency in China is generally improving (decreasing) from 0.301 in 2001 to 0.268 in 2011. The average overall inefficiency in these 11 years for China is 0.270, implying that about 30 % of the resources used in China can be saved with respect to its own efficiency frontier. China is a country in short of per capita natural resources. Efficient use of resources for China is not only beneficial to China itself but also to the whole world.

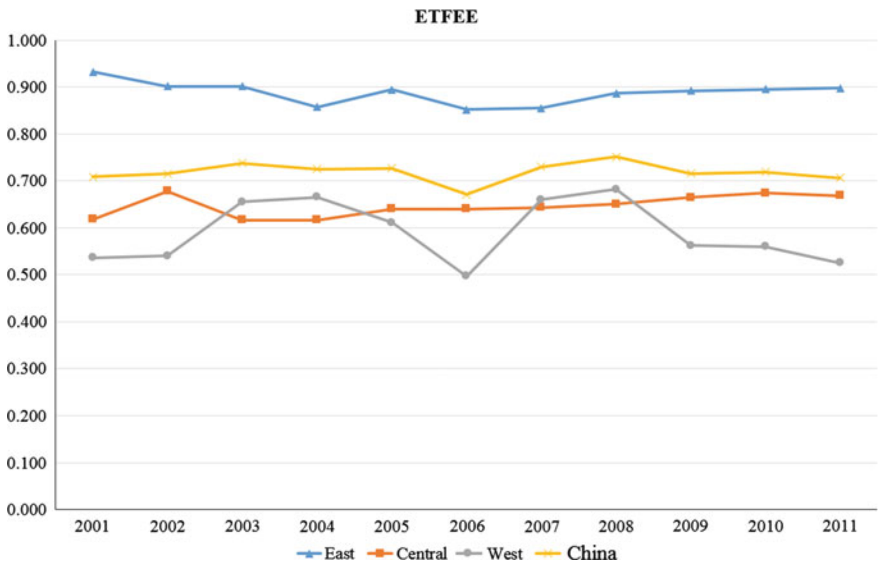


Area/Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Average
East	0.081	0.088	0.086	0.117	0.101	0.129	0.119	0.110	0.104	0.097	0.100	0.103
Central	0.338	0.353	0.352	0.350	0.341	0.328	0.350	0.341	0.338	0.323	0.328	0.340
West	0.514	0.470	0.314	0.283	0.523	0.456	0.305	0.283	0.430	0.405	0.403	0.399
China	0.301	0.293	0.238	0.238	0.312	0.297	0.247	0.234	0.281	0.265	0.268	0.270

Fig. 5.2 Average overall inefficiency scores in China (2001–11). *Source* Authors' calculation

As Fig. 5.3 shows, ETFEE rankings for three major areas are east (0.888), central (0.646) and west (0.590) during the period 2001–11. Meanwhile, ETFPE rankings for three major areas are east (0.857), central (0.529), and west (0.415). These rankings are the same as those in overall inefficiency. However, as illustrated in Figs. 5.3 and 5.4, an ETFPE score is always lower than an ETFEE score for the same area in the same year. The ETFEE is China remains stable from 0.709 in 2006 to 0.706 in 2011, but the ETFPE gradually worsens from 0.671 in 2001 to 0.533 in 2011. Indeed, all three areas show a worsening trend in pollution efficiency from 2009 to 2011.

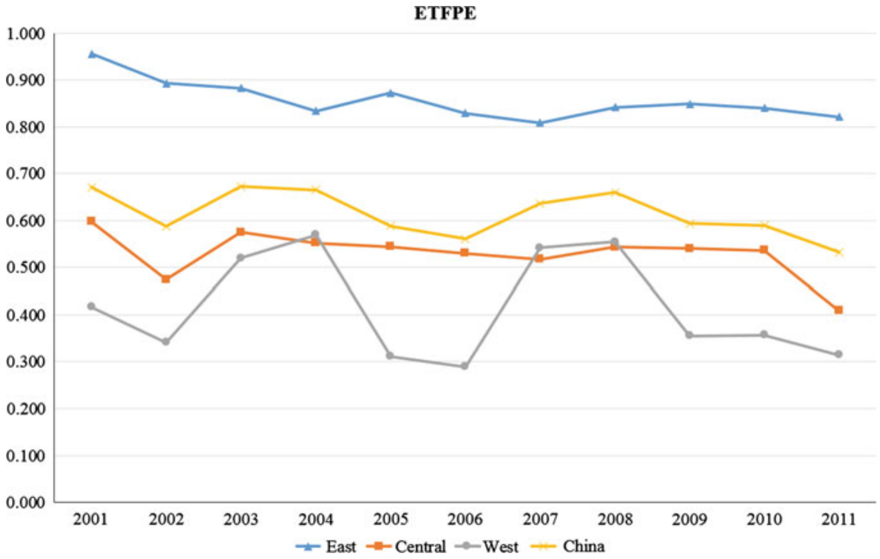
Our empirical findings show that the east area always has higher overall technical efficiency (lower inefficiency), ecological total-factor energy efficiency, and ecological total-factor pollution efficiency than the other two areas during the period 2001–11. However, the scores of overall inefficiency, ecological total-factor energy efficiency, and ecological total-factor pollution efficiency of the central and west areas surpass each other in different years. This result implies that the richest area in China has the highest efficiency scores (3 types) in each year of the sample period.



Area/Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Average
East	0.932	0.901	0.901	0.857	0.894	0.852	0.855	0.887	0.892	0.895	0.897	0.888
Central	0.618	0.678	0.616	0.617	0.640	0.640	0.644	0.650	0.665	0.674	0.669	0.646
West	0.536	0.540	0.655	0.666	0.611	0.497	0.660	0.682	0.562	0.560	0.525	0.590
China	0.709	0.715	0.738	0.725	0.726	0.671	0.730	0.751	0.715	0.718	0.706	0.719

Fig. 5.3 The ecological total-factor energy efficiency scores in China (2001–11). *Source* Authors' calculation

There is also an important insight from the empirical results: during the period of the 11th Five-Year Plan, some regulations were launched in order to reduce pollutant emissions, such as the introduction of desulphurisation equipment and the shutdown of small power units with low energy efficiency. Accordingly, it is expected that energy and pollution efficiencies should increase progressively. Based on the data, conventional energy efficiency (GDP/energy-consumption ratio) has been enhanced by about 25 % and SO_2 intensity (SO_2-emission/GDP ratio) has decreased by more than 50 % from 2006 to 2011, indicating that the launched regulations are effective. However, our results suggest that ETFEE has improved by only 5 %, while ETFPE has decreased around 6 % from 2006–11. This implies that the catch-up effects of energy consumption and pollutant emission are positive but that the speed of catch-up is relative low.



Area/Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Average
East	0.956	0.892	0.883	0.834	0.872	0.829	0.808	0.842	0.849	0.840	0.821	0.857
Central	0.598	0.474	0.575	0.552	0.544	0.530	0.517	0.543	0.540	0.536	0.409	0.529
West	0.417	0.341	0.520	0.570	0.311	0.289	0.542	0.554	0.355	0.357	0.315	0.415
China	0.671	0.587	0.673	0.665	0.588	0.560	0.636	0.660	0.593	0.590	0.533	0.614

Fig. 5.4 The ecological total-factor pollution efficiency scores in China (2001–11). *Source* Authors' calculation

5.4 Conclusions

As the world's largest energy consumer and major pollutant discharger, China is facing a dual challenge of improving both energy and emission efficiencies. In order to accurately monitor energy and emission efficiencies, this study proposes two indices: ecological total-factor energy efficiency and ecological total-factor pollution efficiency. During the sample period of 2001–11, the ecological total-factor pollution efficiency is always lower than the ecological total-factor energy efficiency for any area in China in the same year. The empirical results support the fact that China is facing a more serious situation with respect to pollution control than energy saving. This result is consistent with the improving energy intensities but worsening air pollution situations in China's regions.

According to our findings, China should control not only the input side (e.g. energy saving) but also the output side (e.g. air pollution). Replacing the use of coal with natural gas, solar energy, wind power, etc., can help reduce air pollution. Sulphur and carbon capture techniques can also help prevent the air pollutants from spreading into the air. Public transport systems can also reduce the mobile sources of air pollution, especially in cities of China.

"Think globally, act locally." China must continue with efforts at the regional level to deal with this dual challenge of energy saving and pollution reduction. In addition to the command and control instruments, economic instruments at both the national and regional levels can also be applied, such as energy and carbon taxes, carbon right market, subsidies and tax reductions for new technology and equipment, etc. In addition to energy efficiency improvement, if China can continue to improve its pollution efficiency at the same time, then its economic development model can gradually be adjusted to become sustainable, which will not only benefit the Chinese people, but also the rest of the world.

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Chapter 6
The Legal Challenges of Legislation and Policies Relating to Energy Conservation and Energy Efficiency in China

Haifeng Deng

Abstract China's basic legislation and policy framework on energy conservation and energy efficiency consists of four basic slip laws, scores of administrative rules and regulations, and several basic national plans. This framework is the foundation of energy conservation. The basic systems included in China's legislation and policies are: the energy conservation target responsibility and evaluation system, energy conservation of key energy-consuming entities, the energy conservation standards system and the energy efficiency label system. These play important roles in energy conservation and energy efficiency improvement. Though China has made some progress, there remain three obstacles. First, the energy law system is not sound and the administrative management system is unreasonable. Second, the various differences in legislation pertaining to energy conservation and climate change make them difficult to integrate. Third, there exist many challenges in the enforcement of energy conservation and energy efficiency systems, issues that need to be solved so as to achieve the goal of energy conservation and energy efficiency improvement.

Keywords Legal challenges · Energy conservation and efficiency · China

6.1 Introduction

Energy is fundamental for the survival and development of human society. It has become one of the dominating factors in domestic economic growth due to the influence of the Industrial Revolution.[1] China is presently in the stage of accelerated

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[1]For example, "the development of industrial economy in Western countries is closely related with oil. From the beginning of [the] 1950s, their economy were booming. The United States achieved a 4.3 % increase; Italia increased by 7.6 %; France increased by 9.1 %. An important reason of it is the consumption of cheap oil in quantity" (*Economic Growth and Petroleum Security* 2013).

B. Su and E. Thomson (eds.), *China's Energy Efficiency and Conservation*,
SpringerBriefs in Environment, Security, Development and Peace 31,
DOI 10.1007/978-981-10-0928-0_6

industrialisation and urbanisation. In order to achieve the goal of sustainable development, it is necessary to adjust the mode of economic growth, which greatly relies on the transformation of energy utilisation.

Energy utilisation refers to both the amount *and* efficiency of energy use. Recent statistics show that China is one of the world's leading consumers of energy—in 2013, China accounted for 22.4 % of the world's primary energy consumption (BP 2014), whereas it provided only 12.3 % of GDP (Xinhuanet 2014). According to the report by the World Economic Forum and Accenture Management Consulting Company, China ranks only 74th in industrial energy efficiency in the world (Sun 2013). Hence, China has the responsibility to save energy and increase energy efficiency, and legislation and policies play a significant role in the process.

6.2 Basic Legislation and Policy Frameworks Relating to Conservation and Energy Efficiency

China launched its energy legislation since the Reforms and Opening Up, especially during the two decades starting from the 1990s. During this period, the four pillars of the energy legal system—the Electric Power Law (2009);[2] the Coal Law (2013);[3] the Energy Conservation Law (2007);[4] and the Renewable Energy Law (2009)[5]—were enacted and issued in succession. There are currently over 200 administrative regulations and departmental rules at the national level. In addition, energy conservation and energy efficiency have become more and more important in the national economic and social development plan.

These basic slip laws, administrative rules and regulations, and fundamental national plans constitute the key legislation and policy frameworks for China's energy conservation and efficiency efforts. We focus here on the basic laws and basic national plans herein.

[2]Standing Committee of the National People's Congress [全国人大常委会], adopted on 28 December 1995, revised on 27 August 2009.

[3]Standing Committee of National People's Congress, adopted on 29 August 1996, revised on 29 June 2013.

[4]Standing Committee of National People's Congress, adopted on 1 November 1997, revised on 28 October 2007.

[5]Standing Committee of National People's Congress, adopted on 28 February 2005, revised on 26 December 2009.

6.2.1 Basic Laws

6.2.1.1 Energy Conservation Law

Compared with the three other basic laws, the Energy Conservation Law is the central component of the whole framework. It aims to "promote energy conservation in the whole society, enhance energy utilisation efficiency, protect and improve the environment, and thus promote comprehensive, coordinated and sustainable development in the economy and society."[6]

According to the Energy Conservation Law, the promotion of energy efficiency is considered an important method of energy conservation in China. The Energy Conservation Law can be applied to the saving of energy in the construction and transportation industries, and public institutions. It not only regulates the energy use of these entities, but also emphasises the management responsibility of government and relevant departments. In 2007, the Energy Conservation Law was revised to help realise the energy conservation goal put forward by the Eleventh Five-Year Plan for National Economic and Social Development (abbr. Eleventh Five-Year Plan).[7]

6.2.1.2 Renewable Energy Law

In China's energy structure, fossil fuels account for over 90 % of energy consumption, especially coal and petroleum.[8] However, China's per capita consumption of coal, petroleum and natural gas accounts for only 67, 5.4 and 7.5 % of the world's average (The Information Office of the State Council 2012). Therefore, the exploitation and utilisation of renewable energy is crucial to China's energy supply and energy security. That was why the Renewable Energy Law was passed in 2005.

6.2.1.3 Electric Power Law and Coal Law

The Electric Power Law is the starting point of China's energy slip laws. It regulates electricity production and operating activities on the governing principle of "saving electricity".[9]

Similarly, the Coal Law also regulates the behaviour of coal-mining enterprises. The energy conservation and energy efficiency clause is in Article 24(1): "The

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[6]Article 2, Energy Conservation Law.

[7]The 10th National People's Congress [第十届全国人大], was adopted on 14 March 2006. The plan is made every five years, and the Eleventh Five-Year Plan was for 2006–10.

[8]In 2011, the percentage of coal and petroleum in total energy consumption was 72 % and 19.5, and that of natural gas was 5.2 % (Department of Energy Statistics of National Bureau of Statistics, 2012, p. 52).

[9]See Article 24, Electric Power Law.

exploitation of coal resources must comply with coal mining regulations, follow the rational mining sequence and achieve the rate of extraction set for exploiting coal resources."

6.2.2 Basic National Plans

Basic national plans give expression to policies in China. In many cases, these are more like guidelines in the field of energy conservation and energy efficiency improvement,[10] though no less vital than legislation in practice.

6.2.2.1 The Eleventh Five-Year Plan and the Twelfth Five-Year Plan for National Economic and Social Development (Abbr. Twelfth Five-Year Plan)[11]

The Five-Year Plan for national economic and social development dominates over all other national plans. The grand blueprint of China's economic and social development in the next five years, it is also the program of action for Chinese citizens and provides important criteria for the government.[12]

The Twelfth Five-Year Plan highlights the importance of energy conservation and features two innovations: first, energy conservation becomes a part of the guiding thoughts in economic and social development;[13] and second, it connects energy conservation with the control of greenhouse gas emissions and the response to global climate change.[14]

6.2.2.2 The Eleventh Five-Year Plan for Energy Development (Abbr. Eleventh Energy Plan)[15] and the Twelfth Five-Year Plan for Energy Development (Abbr. Twelfth Energy Plan)[16]

China's energy development plans are based on the five-year plan for national economic and social development, its grand blueprint and program of action.

[10]For instance, the Eleventh Five-Year Plan was earlier than the Energy Conservation Law to provide the energy conservation target responsibility system.

[11]The 11th National People's Congress [第十一届全国人大], adopted on 14 March 2011.

[12]See the Eleventh and Twelfth Five-Year Plan.

[13]See Chap. 2, Part I, the Twelfth Five-Year Plan.

[14]Energy conservation and energy efficiency is mentioned several times in Part VI: Positive Response to Global Climate Change.

[15]National Development and Reform Commission [国家发展和改革委员会], issued in 2007.

[16]The State Council [国务院], issued on 1 January 2013.

The Eleventh Energy Plan calls for the perfection of the energy legal system, including the revision of the Coal Law, Electric Power Law and Energy Conservation Law, as well as the enactment of the Energy Law, Oil and Gas Law, etc.[17]

The Twelfth Energy Plan thus strengthens the control requirements in energy conservation, regulating the energy intensity[18] and total energy consumption in the meantime.[19] It further specifies and quantifies the tasks for and requirement of energy conservation in relevant fields and sectors.[20]

6.2.2.3 Energy Development Strategy Plan of Action (2014–2020)[21]

The General Office of the State Council published the Energy Development Strategy Plan of Action (2014–2020) on 7 June 2014. Several new ideas were proposed. For instance, the "one connection, double control" system was proposed to control the rapid growth of energy consumption, while the "top runner" system was to promote energy efficiency. "One connection" means that energy consumption should be connected with economic development. "Two control" is to strongly control the total energy consumption of industries that are energy-intensive or are at overcapacity, and to strongly control other industries based on advanced energy efficiency standards.

6.3 Basic Systems of Energy Conservation and Energy Efficiency

6.3.1 The Energy Conservation Target Responsibility and Evaluation System[22]

The energy conservation target responsibility and evaluation system is an energy management system in which the central government distributes the energy conservation target to lower-level governments responsible for energy conservation in their own administrative regions, and where the completion rate of the energy conservation target is included in the comprehensive evaluation of local economic

[17]See Chap. 6, the Eleventh Plan for Energy Development.

[18]Energy intensity refers to the ratio of total energy consumption to gross domestic product in a country, or the energy consumption per unit of GDP output.

[19]See Sect. 2, Chap. 2, the Twelfth Plan for Energy Development.

[20]The State Council, issued on 6 August 2012.

[21]The State Council, issued on 7 June 2014.

[22]The energy conservation target responsibility and evaluation system only refers to one that is aimed at local governments and officials in charge.

and social development and the performance of local governments and officials in charge. The purpose of the system is to make local governments concerned about energy conservation and energy efficiency so that they are willing to promote the realisation of the energy conservation target set by the Central Government.

At the national level, it was the 11th Five Year Plan that first included the energy conservation target responsibility and evaluation system.[23] It was then elaborated upon in two normative documents of the State Council known as The State Council's Decision on Strengthening Energy Conservation Work[24] and The State Council's Notice of Issuing the Comprehensive Work Plan on Energy Conservation and Emission Reduction (abbr. 2007 Work Plan).[25] In 2007, the revised Energy Conservation Law accepted it in Article 6,[26] improving its legal status.

As previously mentioned, the energy conservation target is set in the Eleventh Five-Year Plan for National Economic and Social Development. The National Development and Reform Commission is authorised to distribute a target to each province, taking into consideration factors such as the request of local governments, level of development, industrial structure, energy consumption per unit of GDP, total energy consumption, per capita energy consumption, level of energy self-sufficiency, etc.[27] If a provincial government fails to meet the target and the evaluation result is 'undone', the officials in charge will not win any annual awards or honorary titles, and the ratification and examination on new construction of energy-intensive projects will be suspended. This is referred to as the "one-vote veto". On the contrary, governments classified as meeting 'fulfilment' or "over-fulfilment" will be granted the energy conservation targets and rewarded.[28]

6.3.1.1 Results

Shanghai, Zhejiang, Jiangsu, Shandong, Hebei, Gansu and some other provinces added "energy conservation" to the evaluation system of officials (Mo 2008: 138). According to official resources, all provinces except Xinjiang reached the target set by the Reduction Index in Eleventh Five-Year.[29]

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[23]Section 6, Chap. 22, Part VI.

[24]The State Council, issued on 6 August = 2006.

[25]The State Council, issued on 23 May 2007.

[26]Article 6: "The State implements the energy conservation target responsibility system and the energy conservation examination system".

[27]See the State Council (17 September 2006). Approval on the Plan of Reduction Index of Energy Consumption Per Unit of GDP in All Regions in the Eleventh Five-Year Period (abbr. Reduction Index in Eleventh Five-Year) [国务院关于 "十一" 期间各地区单位生产总值能源消耗降低指标计划的批复].

[28]See National Development and Reform Commission (17 November 2007). Implementation Plan on the Evaluation System of Energy Consumption Per Unit of GDP [单位GDP能耗考核体系实施方案].

[29]See Work Plan in Twelfth Five-Year.

6.3.2 Energy Conservation of Key Energy-Consuming Entities

"Key energy-consuming entities" refer to those with an annual energy consumption of more than 10,000 tons of standard coal; and those designated by relevant departments of the State Council or the energy conservation administrative departments of provincial governments, which have an annual energy consumption of between 5,000 to 10,000 tons of standard coal.[30] Key energy-consuming entities are major consumers in industrial energy consumption. In 2006, 922 key energy-consuming enterprises in the most energy intensive industrial sectors occupied 31.5 % of total primary energy consumption in China (An 2007: 47).

Key energy-consuming entities have legal obligations to submit reports on energy utilisation during the previous year to the energy conservation administrative department,[31] and to set up energy management posts and employ persons specialising in energy conservation.[32]

For better implementation of the system, the National Development and Reform Commission initiated the "Top 1,000 Enterprises Action" in 2006.[33] To some extent, it was the energy conservation target responsibility and evaluation system designed for enterprises. The "Top 1,000 Enterprises Action" was intended for 1,008 independent accounting enterprises in nine top energy-consuming industrial sectors[34] to help save 100 million tons of standard coal in five years. These enterprises signed the "energy target responsibility statements" and promoted technical reform of energy conservation. In addition, the energy utilisation situation or the evaluation results were publicised for social supervision. As the Twelfth Five-Year Plan put more pressure on energy conservation, the Central Government launched the "Top 10,000 Enterprises Action", which extended to enterprises taking up over 60 % of China's energy consumption.[35]

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[30]See Article 52, Energy Conservation Law.

[31]See Article 53, Energy Conservation Law.

[32]See Article 55, Energy Conservation Law.

[33]See National Development and Reform Commission [国家发展和改革委员会] (7 April 2006). Notice of issuing the 1,000 Enterprises Energy Conservation Program Implementation Plan (abbr. 1,000 Enterprises Implementation Plan) [关于印发千家企业节能行动实施方案的通知].

[34]The nine sectors are iron and steel, nonferrous metals, coal mining, electric power generation, petroleum and petrochemicals, chemicals, construction materials, textiles and paper making. See 1,000 Enterprises Implementation Plan.

[35]Specifically, it refers to entities that have annual energy consumption of more than 10,000 tons of standard coal, and entities designated by relevant department that have annual energy consumption of more than 5,000 tons of standard coal. See National Development and Reform Commission (7 December 2011). Notice of issuing the 10,000 Enterprises Energy Conservation and Low Carbon Program Implementation Plan [关于印发万家企业节能低碳行动实施方案的通知].

6.3.2.1 Results

By the end of 2010, there are 881 enterprises[36] in the program.[37] The "Top 1,000 Enterprises Action" hit its promised target and decreased the usage of 150 million tons of standard coal[38] (Policy Research Office of National Development and Reform Commission 2011) thanks to a stronger management and incentive mechanism.

6.3.3 Energy Conservation Standards

Energy conservation employs the use of high technology. For example in the proposal process and assessment of the energy conservation target, the energy conservation standard is examined on a technical basis. The energy conservation standard is a like a ruler used to measure the effectiveness of energy conservation in sources, and it is also applied to set reasonable thresholds for market access. Therefore, it is the world's prevailing energy conservation management system prevailing (Xiao/Xiao 1996: 114).

There are multiple energy conservation standards in China: national, local, industrial and enterprise standards. Local standards and enterprise standards, if any, have to be stricter than national and industrial standards.[39] Among these, national, industrial and enterprise standards are effective nationwide, while local standards are only binding in their own region. Though used on a smaller scale, it is necessary to have a local energy conservation standard, because all regions differ in economic development levels, industrial structure and, above all, in energy structure. However, the possibility of regional trade protection caused by a higher local standard is worth taking into consideration (An 2007: 23).

There are 15 provisions concerning the establishment and function of the energy conservation standard system in the Energy Conservation Law. On the one hand, it emphasises the importance of establishing and improving the energy conservation standard system.[40] On the other hand, the energy conservation standard system is expected to play a vital role in energy conservation management. For example, manufacturers of energy-intensive products should implement the standard set for

[36]The number fell from 1,008 to 881 because of merger, bankruptcy or suspension.

[37]See National Development and Reform Commission (2 December 2011). No. 31 Announcement in 2011.

[38]According to National Development and Reform Commission No. 31 Announcement in 2011, the amount is 165 million tons of standard coal.

[39]See Articled 13(2) and (3), Energy Conservation Law.

[40]See Article 13(1), Energy Conservation Law.

it. If a manufacturer consumes energy in excess of the standard, it will be ordered to make rectifications within the time limit.[41]

The National Development and Reform Commission and Standardization Administration of China jointly launched the "100 Energy Efficiency Standards Project" in June of 2012 (NDRC 2012). As the project title suggests, it means to enact or revise 100 important energy standards to promote energy conservation and industrial restructuring. By the end of that same year, 54 national standards had been formulated and released (Standardized Administration of the P.R.C. 2013)

6.3.4 Energy Efficiency Label

The energy efficiency label indicates the energy efficiency grade and other performance indices of energy-consuming products.[42] There are five grades defined on the basis of energy efficiency standards—Grade 1 signifies that the product has the lowest possible energy consumption while Grade 5 is the grade for market access. Products that consume more energy than the requirement of Grade 5 are not allowed to be produced or sold (An 2007: 32).

The energy efficiency label system came into effect in March 2005, and it started with household refrigerators and room air-conditioners.[43] It was provided in the Energy Conservation Law that China "implements energy efficiency label management to household appliances and other energy consuming products that are widely used and consume much energy."[44] As for the administration of the energy efficiency label, China adopts the filing system—in which manufactures and importers can determine the energy efficiency grade for products in national energy efficiency label management catalogues by themselves or using testing organisations recognised by the CNCA[45], and then file to the institution jointly authorised by the product quality supervision department and the energy administrative department under the State Council.[46]

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[41]See Article 16(2), Energy Conservation Law.

[42]National Development and Reform Commission, General Administration of Quality Supervision, Inspection and Quarantine (13 August 2004). Measures for the Administration of Energy Efficiency Labels [能源效率标识管理办法].

[43]See National Development and Reform Commission, General Administration of Quality Supervision, Inspection and Quarantine, Certification and Accreditation Administration [国家认证认可监督管理委员会] (29 November 2004). Notice No. 71 of 2004: Attachment 1.

[44]Article 18, Energy Conservation Law.

[45]Article 9, Measures for the Administration of Energy Efficiency Labels.

[46]Article 19(1), Energy Conservation Law.

6.3.4.1 Results

To date, there have been ten catalogues including about 30 sorts of products.[47] The "Energy-Saving Products Benefit Project" launched in 2009 is the adaption and popularisation of the energy efficiency label. It aimed to popularise the application of ten kinds of products of Grade 1 or above Grade 2 through fiscal subsidies, and increase the market shares of high-efficient and energy-saving products by 10–20 % (NDRC 2009). By the end of March, 2011, the project had helped save 22.5 billion kilowatt hours of electricity (NDRC 2011).

6.4 Challenges and Solutions

Energy conservation has been considered the "cheapest, fastest and most environmental friendly way to reduce energy demand" (Ye 2007: 5) and is taken seriously in China. Similarly, energy efficiency improvement has become an essential component in national energy legislation and policies, and many prevailing or advanced measures from different parts of the world have been introduced in China. However, China faces three major challenges that should not be ignored—they need to be tackled successfully in order for improvements to be made in energy conservation and energy efficiency.

6.4.1 Defects in the Energy Administrative System and the Energy Law System

Presently at the national level, there is no exclusive department for energy management and relevant work. As a result, the roles and responsibilities concerning the regulations of the energy industry are shared by several departments within the Central Government. For example, coal, oil, nuclear and other mining rights are managed by the Ministry of Land and Resources; the National Development and Reform Commission is responsible for investment of energy and energy conservation, and it also co-manages the electric power with the National Energy Administration; the Ministry of Agriculture and State Forestry Bureau jointly take charge of biomass energy; and the Ministry of Industry and Information Technology oversees industrial energy management. In addition, the majority of major enterprises in the energy industry are state-owned, so they also come under the administration of the Standardization Administration of China (Xiao 2012: 7). In theory, the National

[47]The tenth catalogue was published by the National Development and Reform Commission, General Administration of Quality Supervision, Inspection and Quarantine and Certification and Accreditation Administration in Notice No. 39 of 2012 on 14 November 2012.

Energy Administration is the supervising department in charge,[48] but it is in practice only a national bureau that is of a lower administrative level than most departments. Thus, the National Energy Administration does not have say over law-making and policy-setting on energy conservation and energy efficiency.

It is not hard to find the four defects of the energy law system through a comprehensive analysis. These comprise structural defects, content defects, matching defects and coordination defects (Ye 2008: 5).

Structural defects arise from two areas. On the one hand, the absence of a comprehensive and basic Energy Law has aroused public concern. On the other hand, there are also vacancies in the subsystem of energy law. Specifically, the slip laws on oil, natural gas, atomic energy and public utilities of energy have been in absence for a long time.

Content defects come about when some particular legislation in force is in need of revision because it is ill-adapted to the tendency of energy reform and the desirability of a market economic system.

Matching defects occur when provisions in existing energy slip laws are usually issued only in principle, and a number of administrative regulations and rules are required to put these laws into effect. Unfortunately, some rules and regulations came up only several years after the issue of slip laws, or were otherwise forgotten.

Coordination defects arise from discordance in legislation within the same legal hierarchy, as well across different legal hierarchies. For example, the Electric Power Law, Coal Law, Energy Conservation Law and Renewable Energy Law all belong to the same legal hierarchy, but are totally separated in the energy field and law-enforcing departments.[49] Such coordination defects make it difficult for the laws to bring about effective results in energy conservation (Xiao 2012: 7).

All four defects, especially structural, matching and coordination defects, have arisen from the fragmentised and instable energy administrative system, the latter of which we examine below.

First, China's energy administrative system assigns legislations and policies to department-levels, leading to competition among the various departments and eventual delays in legislation. The formulation of the Energy Law is a typical case in point—the drafting of it began as early as January 2006 but, to date, it has yet to be finalised. In the current legislative system, 15 departments are delegated by the State Council to jointly draft the Energy Law. However, the drafting work came to a deadlock in the initial stage of talks and exchanging of opinions. Participating

[48]See General Office of the State Council [国务院办公厅] (9 June 2013). Notice of Issuing the Regulation on the Main Functions, Internal Institutions and Staffing of the National Energy Administration [关于印发国家能源局主要职责内设机构和人员编制规定的通知].

[49]It is provided that the electric power administrative department, coal administrative department, energy conservation administrative department and energy administrative department under the State Council are respectively responsible for supervision and control of the electric power industry, coal industry, energy conservation and renewable energy. See Article 6 of Electric Power Law, Article 12 of Coal Law, Article 10 of Energy Conservation Law and Article 6 of Renewable Energy Law.

departments could not stop bargaining with one another for their own authority and benefits under the pretext of protecting the interests of the country and maintaining the current legal provisions and system (Xiao 2012: 10).

Second, the system explicitly stipulates, in its slip energy laws, that specific measures to implement some provisions should be formulated by relevant departments under the State Council. But due to the system's fragmented and unstable nature, either no department undertakes the organisation of drafting work, or there are great difficulties in cross-department coordination, or the departments in charge are removed or merged. As a result, certain measures provided in the slip laws cannot be carried out in practice.

Third, the disjointedness of China's energy administration system also results in situations in which legislation (especially administrative rules and regulations) on one energy sub-industry may come from multiple departments, e.g. the management of the coal industry. To be more precise, nine departments are in charge of the coal industry in different aspects, such that the complete industrial chain is extremely segmented.

From the above discussion, it is evident that the most pressing matter is to refine the energy management idea and streamline the mode of administration in the legislation process of Energy Law. The energy administrative system should reorganise its structure to avoid the embarrassment of incompatible rules coming from several departments on the same issue.

To better establish the legal system with respect to energy and to promote the development of energy in China, the Energy Law will soon be made to fill the gap in the energy law system. It should be in a higher hierarchy to coordinate the content of different levels and of different effects. Further, it should play a leading role in the energy law system, especially in the energy conservation law system. In a word, based on the consideration of the overall effectiveness of sustainable development, the Energy Law should justify the adjustment range of slip laws and make it possible to form a resultant force in the whole energy legal system (Deng/Zhao 2011: 31).

6.4.2 The Challenge of Integrating Legislation on Energy Conservation and Climate Change

Climate change is one of the most daunting challenges faced by all countries in the process of global development. The emission of greenhouse gases is recognised as the main cause for climate change. Hence, reduction of greenhouse gas emission and the control of climate change always go hand in hand with energy conservation and energy efficiency improvement. Though energy conservation laws such as the Energy Conservation Law and the Renewable Energy Law have been put into effect and provide some mitigation measures in response to climate change, there is no special legislation for climate change control in China. The National Development and Reform Commission is leading the draft of the Climate Change Response Law, bringing the task of climate change control in China from policy to legislation. Thus, China has to endeavour to perfect the legislation on energy conservation and energy efficiency, and integrate it with climate change legislation at the same time. There are two key distinctions between energy conservation legislation on energy conservation and energy efficiency and legislation on climate change.

First, they differ in the hierarchy of value target. Energy conservation and energy efficiency improvement are both means to control the consumption of energy and guarantee the sustainable supply of energy—so they can be classified into legal measures at the technical level. On the contrary, the response to climate change refers to human beings' endeavour to adapt to objective laws of the ecosystem itself. Climate change legislation is a direct manifestation of the scientific understanding that human beings are not the dominators of the world, but only parts of the ecosystem. On account of this, climate change legislation belongs to ecological law at value level and it has higher legal value and is higher up on the legal hierarchy than energy conservation and energy efficiency legislation, which are specific technical measures.

Second, the two kinds of energy legislation and the legislation on climate change differ in effect due to the difference of purpose and means. According to the United Nations Framework Convention on Climate Change and other international instruments or foreign legislation, the basic framework of climate change response law can be described as "one body with two wings". "One body" refers to the comprehensive response law, which establishes the basic principles and basic legal systems for climate change response. And "two wings" refer to mitigation legislation and adaptation legislation, which correspond exactly to the two aspects in climate change response (Zhang 2010: 37). Energy conservation and energy efficiency legislation represent mitigation legislation, because they will result in a decrease in the emission of greenhouse gases and help promote the "green update in economy" (meaning "sustainable development", a term used in Chinese law). Therefore, energy conservation and energy efficiency legislation is a means to slow down climate change and also aid in the sustainable development of mankind.

At present, it is recognised in international society that sustainable development is the only effective way to solve the problem of climate change (Zhuang 2004: 50). In other words, climate change control is one of the goals of sustainable development and is a typical purpose behaviour, i.e. the behaviour itself being one of the aims of the legislation. In order to form a comprehensive green development legal framework, energy conservation and energy efficiency need to be integrated into climate change legislation.

6.4.3 Challenges in Enforcement

The law alone is not enough; the enforcement of legislation often plays a dominant part in limiting the process of rule of law in China. The same goes for the enforcement of energy conservation and energy efficiency legislation. Challenges in enforcement could be attributed to the following.

Initially, unbalanced economic development results in the differences in ability and willingness to enforce laws among provinces. Legislation on energy conservation and energy efficiency improvement needs to be implemented by provincial governments, but local governments' practices are not always consistent with the Central Government's. This is chiefly due to the large gap between rich and poor provinces.[50] To be specific, firstly, demand for development varies in each province, as does demand for energy. Secondly, the level of energy-saving technology and financial investment differs among provinces. Thirdly, as provinces have also already become leaders in energy conservation, it is difficult for them to save more energy. Besides, local governments have to sacrifice the benefits brought about by energy-intensive projects, i.e. increased employment and tax, and social stability that result from the labour-intensive nature of industries involved in energy-intensive projects. This is why the majority of local governments tend to deregulate energy-intensive industries, especially during economic downturns when they are under great pressure to sustain growth.

Presently, the lack of punishment measures in place for those who flout energy legislation is another challenge faced in the enforcement of such legislation. The imposition of sanctions is the ultimate guarantee of enforcement—if there are no penalties for the failure to enforce laws, especially when there are relevant provisions in laws, the authority of law is in doubt, and the vicious cycle continues.

Relevant examples are countless—the implementation of the energy conservation target responsibility and evaluation system in the "Twelfth Five-Year" being a case in point. In 2011, the first year of the "Twelfth Five-Year", there were six provinces—including Zhejiang, Hainan, Gansu, Qinghai, Ningxia and Xinjiang—that did not meet the annual energy conservation target. In addition, there were another six provinces that completed the annual task but fell behind the rate of progress of the five-year energy conservation schedule.[51] The slack in energy conservation work of those provinces could be attributed to the fact that punishment measures were not in place.

Next, the effect of specific systems needs to be tested in practice, especially the systems that have not come into effect for a long time, and where little analysis exists about their comprehensive effectiveness.

For instance, under the stimulating policy of financial subsidies, the energy efficiency label is widely known by consumers in relevant industries, especially by the buyers of household appliances. However, results from the survey on whether

[50]In 2012, the per capita GDP of Tianjin was 93173 RMB, the per capita GDP of Beijing was 87454 RMB and that of Shanghai was 85373 RMB. In the meantime, the per capita GDP of Guizhou and Gansu was only 19710 RMB and 21978 RMB (National Bureau of Statistics 2013).

[51]Another six provinces are Inner Mongolia, Liaoning, Jiangsu, Fujian, Jiangxi and Guangdong. See National Development and Reform Commission (18 December 2012). Notice No. 51 of 2012.

consumers trusted the energy efficiency label were not so inspiring. Only half of the consumers chose to trust the authenticity and authority of energy efficiency labels, of which only 4.39 % had full trust in them (Sang 2013). Contract energy management[52] has not been well developed due to the financing problem of energy-saving service enterprises, and there is no better means to evaluate the effect of this advanced system than through actual practice (Geng 2012: 428).

To cope with challenges in energy legislation enforcement, some feasible solutions are outlined as follows.

One possibility is to strengthen the scientificity of the assessment standard for performance of officials. The government performance evaluation has been focusing on GDP for a long period, and it leads to the problem of accelerating economic growth by high input, high emissions and heavy pollution. Recently, the Organization Department of the Central Committee of the Communist Party of China issued the Notice on Improving the Performance Evaluation Work of the Local Party Leading Group and Leading Cadres.[53] This Notice makes it clear that ecological civilisation construction is an important component of evaluation and the weight of the "resources consumption" index needs to be increased. Therefore, it is necessary and possible to bring the energy conservation and energy efficiency standard into the evaluation of ecological civilisation construction and make it more precise for better enforcement.

Another solution lies in improving and perfecting the energy conservation work report system. Though the Energy Conservation Law has the stipulation that local governments should report energy conservation work to the People's Congress at the same level every year, this is not always done. For example, there were no detailed reports on energy conservation work in the government work report of Ningxia in 2012.[54] Thus, the People's Congress at the local level should be stricter with the examination of government work reports and require governments to report energy conservation work precisely and comprehensively.

It is also critically important to pay attention to public participation. The most effective way is to file the environmental administrative public interest litigation against the relevant administrations. Therefore the public interest litigation system should be carefully established by the amendment of administrative procedural law and become a common means to determine if administrations have fulfilled their due obligations and responsibilities.

[52] See Article 66(2), Energy Conservation Law.

[53] The Organization Department of the Central Committee of the Communist Party of China, issued on 6 December 2013.

[54] 6 February 2012. http://www.gov.cn/test/2012-02/06/content_2059314.htm [accessed 5 December 2013].

6.5 Conclusion

To date, China has made great efforts to promote energy conservation and energy efficiency, and has indeed made some progress in legislation and policies. However, notwithstanding these achievements, challenges in these two areas deserve more concern. The defects of energy administration and energy legislation; the challenge of integrating legislation on energy conservation and climate change; and the efficiency of energy law enforcement are three major challenges, among others. Whether these obstacles can be successfully tackled will impact the long-term process of energy conservation and energy efficiency in China. Presently, the country needs the formulation of Energy Law; the reasonable arrangement of energy administration; the better integration of energy conservation and climate change legislation; and the settlement of difficulties in law enforcement—and admittedly, it will take a lot of time and wisdom to resolve these issues.

Recently, the price of oil dropped sharply. The lower price may result in more energy consumption and less incentive for energy-intensive industries to carry on with technological improvements. It is necessary for China to pay close attention to such changing circumstances and to come up with energy conservation strategies in the context of cheap energy.

Drafting of the 13th Five Year Plan has not yet started, so there is currently a degree of uncertainty over the state of energy policy in China. Therefore, China should grasp the opportunity of the formulation of the 13th Five Year Plan, and use it to promote the restructuring of the energy industries and enhance the possibility of developing a low carbon economy.

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Chapter 7
Energy Efficiency and Conservation Strategies in Japan and Their Implications in China's Future Energy Development

Mikiko Kainuma and Osamu Akashi

Abstract This chapter describes energy efficiency and conservation strategies in Japan by showing the historical trends of energy consumption and energy efficiency improvements. The Japanese experience demonstrates that efforts to solve environmental problems have served to improve energy efficiency in various fields. A mitigation scenario to halve global GHG emissions by 2050 is presented, and a comparison is done between effective technologies in Japan and China to achieve the target. Although the model analysis shows that a certain set of technologies can improve energy efficiency by 3 % per year and CO_2 intensity with respect to GDP by 3.5 % per year in China by 2050, implementation of the scenario depends on a number of more specific conditions: rates of installation must be achievable; sufficient finance must be mobilised; and barriers to the adoption of low carbon technologies must be overcome. With China's progress in energy efficiency improvement, there are greater opportunities for the country to take further steps in this area so as to contribute not only to economic development and energy security, but also to global climate stabilisation.

Keywords Energy efficiency · Mitigation scenario · CO_2 emissions · Japanese strategy · Chinese strategy · Climate stabilisation

7.1 Introduction

World energy consumption has been increasing since the industrial revolution and the rate of increase has accelerated over the past several decades. It is estimated that more than 1.3 billion people worldwide still lack access to electricity and that about 2.7–3 billion people lack access to modern fuels for heating and cooking (IEA 2010b, 2011). By 2050, growth in population, economic activity, and energy access

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is expected to give rise to a 1.6- to 2.5-fold increase in energy use and energy-related GHG emissions in business as usual (BaU) scenarios. Energy efficiency improvement must therefore be considered on a global scale.

In China, electricity consumption in 2050 is expected to reach 3.5 times the level in 2005 without appropriate reformation of the energy system. This could lead to a worsening of environmental problems such as air pollution and climate change. Reformation of the energy system is also required from the standpoint of energy security.

Energy consumption in Japan has increased since 1960 accompanying the country's economic development. The average increase in GDP was 10 % and that of the primary energy supply was 15 % from 1965 to 1970. With the rise in energy consumption, environmental pollution problems also increased. The four most serious pollution cases were brought to judicial trials: namely, the *itai-itai* disease case (cadmium pollution) in 1968, the Yokkaichi pollution case (air pollution) in 1967, the Niigata Minamata disease case (mercury contamination) in 1967, and the Minamata disease case (also mercury contamination) in 1969. Through these trials, a new interpretation of environment-related issues—including such factors as causality, responsibility, joint outrage, and liability—became a focus of public attention. It was emphasised that in order to prevent environmental pollution, it is not sufficient for enterprises to simply take the best available countermeasures. Rather, they need to make every effort so that there is not even a single victim.

The Law Concerning Special Measures for the Relief of Pollution-Related Health Damage was enacted in 1969. In the 1970s, various approaches to reduce pollution were adopted, such as the introduction of desulphurisation devices, the use of high-quality oil with less sulphur content, and a shift from oil to natural gas. As a result of these measures, air pollutants from industrial plants were drastically reduced.

Through these actions, energy efficiency was greatly improved as the importance of reducing energy consumption in production processes and providing energy-efficient products was recognised.

Countermeasures against automobile exhaust gas emissions were initiated in 1966 with restrictions on the density of carbon monoxide emissions from medium- and small-sized cars in Japan. With the enactment of the Air Pollution Control Law in 1968, these became a formal standard. Automobile exhaust gas emission standards were subsequently strengthened and a succession of new automobiles has been developed to conform to the standards and reduce energy consumption.

The oil crises in 1973 and 1979 became another factor motivating the improvement of energy efficiency in Japan. Energy efficiency was improved by 7.7 % per year in 1975 and 7.1 % per year in 1981 (EDMC 2014). From the 1990s onward, the climate change debate encouraged the development of energy-efficient technologies and policies to support the development and deployment of energy-saving technologies. Efforts to internalise a negative externality have contributed not only to energy efficiency improvement, but also to the reduction of pollutants in Japan.

The Cancun Agreements adopted in 2010 at the 16th Conference of the Parties (COP16) to the United Nations Framework Convention on Climate Change

(UNFCCC) in Cancun, Mexico explicitly refer to the importance of a paradigm shift towards building a low carbon society (LCS) that offers substantial opportunities and ensures continued high growth and sustainable development (UNFCCC 2010). Kainuma et al. (2013) examined the technologies that can support the achievement of an LCS. Realising an LCS entails radical changes in technologies, energy systems, production and consumption patterns, social value systems, and lifestyles, in addition to policy changes that mobilise finance and the willingness of people to achieve such transitions.

China made a pledge to reduce its CO_2 emissions intensity per unit GDP by 40–45 % by 2020 compared with the 2005 levels at COP16. To achieve the Cancun target, China has set a target of decreasing its CO_2 emissions intensity by 17 % by 2015 compared with the 2010 levels in its 12th Five Year Plan. In order to reach the CO_2 intensity target, the State Council released Document No. 41 in December 2012 to provide concrete measures by 2015 (State Council 2012). These are to achieve an energy conservation capacity of 300 million tons of coal equivalent (tce), to attain an 11.4 % share of non-fossil energy consumption in primary energy consumption, to reduce GDP energy intensity by 16 %, to increase the area of forests by 12.5 million hectares, to increase forest coverage to 21.66 %, and to increase the volume of forest stock by 600 million m^3 (Jin et al. 2013). The reduction of GDP energy intensity by 16 % over a period of five years requires an annual average energy efficiency improvement of 3.4 %. These targets need to be strengthened to realise an LCS.

In the following sections, first the historical trends of energy consumption and energy-efficiency improvements in Japan are described together with several Japanese strategies to improve energy efficiency and reduce CO_2 emissions. A mitigation scenario referred to as the LCS scenario, which aims to reduce global GHG emissions by half by 2050, is then presented. Although the model analysis shows that a certain set of technologies can lead to a substantial cut in CO_2 emissions, this has limitations because it is based on certain ideal assumptions, and appropriate actions will be required to introduce the recommended technologies and to meet energy service demand. The opportunities and challenges of the scenario are also discussed in the context of achieving an LCS, followed by the conclusion.

7.2 Policies and Activities to Improve Energy Efficiency in Japan

7.2.1 Historical Trends of Energy Consumption

Primary energy consumption grew at a faster rate than GDP in Japan during the 1970s. The GDP growth rate was 9.5 % per year from 1965 to 1972, whereas the rate of growth in primary energy consumption was 11.4 % per year. However, the oil crises that occurred in 1973 and 1979 affected the Japanese economy and led to

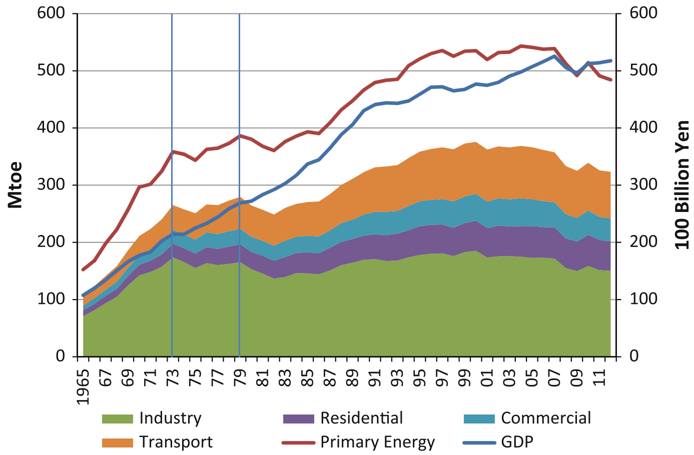

Fig. 7.1 Historical trend of Japan's energy consumption and GDP (1965–2012). *Source* EDMC (2014)

changes in the energy consumption structure. With the country facing restricted oil supplies and a sudden rise in crude oil prices, a shift from oil to gas occurred and the development of energy-saving technologies was promoted from the standpoint of energy security (Fig. 7.1).

The final energy consumption in the industrial sector decreased by 10 % from 1973 to 2012 although GDP increased by 2.4 times during that time. The final energy consumption in both the residential and transport sectors increased by 1.9 times and the total consumption increase was 1.22 times during that period (EDMC 2014). In 1973, the shares of the industrial, residential, and transport sectors were 65.5, 18.1, and 16.4 %, respectively. These values shifted to 46.4, 28.4, and 25.1 % in 2012. Although considerable efforts were devoted to increasing energy efficiency in industrial processes as well as in products after the oil crises, it was difficult to reduce energy consumption in the residential and transport sectors because of the diffusion of comfortable and convenient lifestyles.

Following the first and second oil crises, energy efficiency improved by 7.7 % in 1975 and 7.1 % in 1981. From 1986, oil prices remained stable until 2000. After 2000, oil prices increased again except in 2009, immediately after the Lehman crisis. Energy efficiency decreased in 2010, but improved after 2011.

In the summer of 2011, following the Fukushima nuclear accident, enterprises and commercial buildings that had contracted with Tokyo Electric Power Company (TEPCO) for electricity supplies of 500 kWh per month or more were asked to reduce their peak electricity consumption by at least 15 %, and TEPCO also asked the general public to save power. In response to these calls, final energy consumption was reduced to 0.95, 0.95, and 0.97 times, respectively, in the industrial, residential, and transport sectors from 2010 to 2012. Enterprises and commercial buildings introduced a number of energy-saving technologies such as heat pumps,

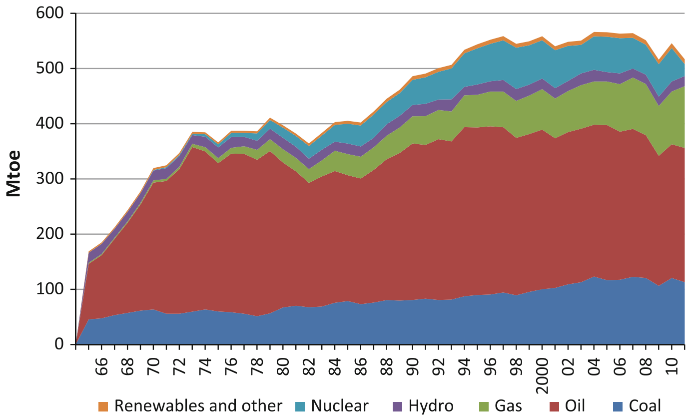

Fig. 7.2 Primary energy supply in Japan (1965–2012). *Source* EDMC (2014)

new types of boilers, and inverters. They also introduced various countermeasures such as rooftop gardening to save cooling energy, and restructuring of supply-chain management. Large numbers of people purchased products incorporating energy-saving technologies such as LED lights, energy-saving refrigerators, and high-efficiency air conditioners. They also switched off unnecessary electric appliances and introduced solar photovoltaic (PV) systems.

The share of oil in the primary energy supply, which was 77 % in 1977, dropped to 44 % in 2010. After the Fukushima accident, however, it increased again, to 48 % in 2012. The share of natural gas increased from 1.5 % in 1973 to 23 % in 2012. The purpose of the shift from oil to gas was not only to reduce the country's dependence on oil, but also to reduce sulphur emissions to conform with the Law Concerning Special Measures for the Relief of Pollution-Related Health Damage enacted in 1969. This law forced polluters to pay the expenses of healthcare for patients and the costs of necessary health welfare programmes under the "polluters pay principle". Enterprises therefore implemented necessary countermeasures such as shifting from oil to gas and installing desulphurisation plants. The share of nuclear power fell from 11 % in 2010 to 1.8 % in 2012 (Fig. 7.2).

7.2.2 *Energy Policies to Improve Energy Efficiency in Japan*

Energy efficiency improvements and shifts in energy resources are taking place in response to the issue of climate change. The Government of Japan (GOJ) set a target of increasing the share of renewable energies to 13.5 % in 2008 and pursues the higher levels by considering the different characteristics of various energy sources, with a view to creating new energy-related industries and jobs (GOJ 2014).

Countermeasures to improve energy efficiency include the Voluntary Action Plans (VAP) formulated by Keidanren (Japan Business Federation), the Top Runner Program, and the greening of the Motor Vehicle Tax System.

The Japanese VAP was initiated in 1997. It was reviewed annually in governmental committees, and an independent third party committee was also established to monitor its implementation; the included industries were constantly required to be accountable with their environmental performance (Keidanren 2014).

The Top Runner Program is a regulatory scheme for electric appliances and vehicles. Under this unique scheme, which was inaugurated in 1998, manufacturers can only sell appliances that match the designated Top Runner efficiency standards. The programme covered 23 types of products as of 2013. Standards are set based on the highest energy efficiency of products on the market according to the fleet average or weighted average. The programme is considered to have been successful. However, Arakawa and Akimoto found that the cost-effectiveness of the programme has recently become less pronounced compared with that in the past due to the high level of technologies now installed (Arakawa/Akimoto 2013).

Figure 7.3 shows a comparison of light-duty vehicle fuel efficiency standards and targets in Japan compared with those in other countries. The establishment of fuel efficiency standards is considered to be one of the best strategies to improve the energy efficiency of vehicles.

The Motor Vehicle Tax System levies different taxes on cars according to their energy efficiency. The reduction in automobile tax is to reduce the tax by approximately 25 % or 50 % from the normal tax rate depending on the emissions performance and fuel efficiency. For an old private vehicle, the tax is increased by approximately 10 % (MLIT 2000).

Extension of the payback time is one of the measures that can be used to promote the introduction of expensive energy-efficient technologies. Figures 7.4 and 7.5 show the marginal abatement costs to reduce GHG emissions in 2030 with

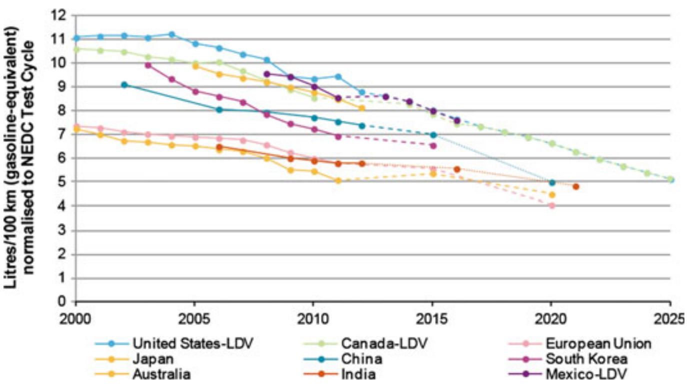

Fig. 7.3 Comparison of light-duty vehicle fuel efficiency standards and targets. *Source* IEA (2013); at: http://www.theicct.org/sites/default/files/publications/ICCTupdate_ChinaPhase4_mar2014.pdf

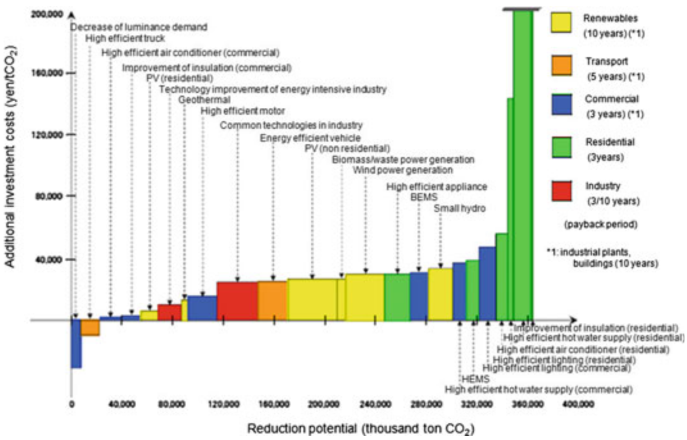

Fig. 7.4 Reduction potential versus additional investment costs in 2030 in high-efficiency case with short payback period. *Source* AIM Project Team (2012)

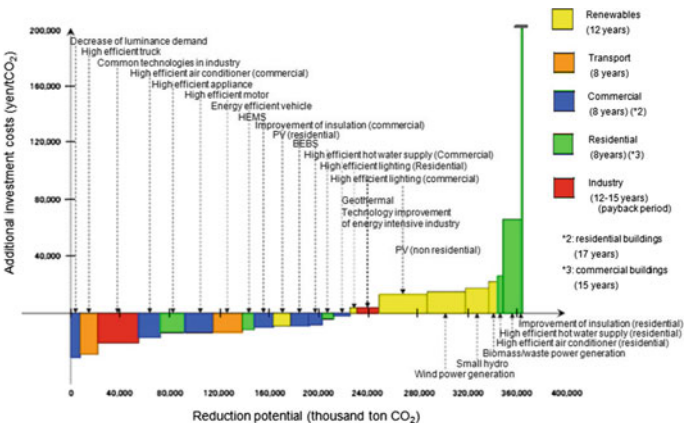

Fig. 7.5 Reduction potential versus additional investment costs in 2030 in high-efficiency case with long payback period. *Source* AIM Project Team (2012)

short-payback and long-payback times in Japan estimated by the Asia-Pacific Integrated Model (AIM) (Kainuma et al. 2003). The adoption of longer payback times could accelerate the introduction of energy-saving technologies and hence give producers the incentive to supply more energy-efficient technologies.

Tokyo Metropolitan Government introduced mandatory targets for reduction in overall greenhouse gas emissions for large-scale emitters. It was Japan's first cap-and-trade emission trading programme and took effect in the 2010 fiscal year. Total emissions for fiscal year 2013 were reduced by 23 % from base-year emissions. The main factor behind this reduction was significant electricity savings by introducing the energy conservation system. According to the survey of the owners of large facilities, 16 % of the owners were willing to extend the payback period while others did not change their minds. minds. 26 % of the owners had introduced energy-saving technologies and 72 % were planning to. They were also interested in using low-carbon electricity (TMG 2015).

7.3 Energy Efficiency Improvement Towards Low Carbon Development in Japan and China

In this section, a Low Carbon Society (LCS) scenario for the reduction of GHG emissions by half by 2050 is used to compare the future energy efficiency improvements required in Japan and China. The scenario was produced using the AIM/Enduse model.

The AIM/Enduse model is a dynamic recursive, technology selection model for the mid- to long-term mitigation policy assessment. The model covers both end-use sectors (transport, industrial, residential and commercial) and the energy supply sector. Non-energy sectors (e.g. agriculture, industrial process, waste) are also included in order to the assess the feasibility of achieving GHG emissions targets. In each sector, service demand, such as steel production, space heating demand in commercial building and passenger transport demand (person-km), is given exogenously and technologies are selected in order to minimise total system cost (annualised initial cost, energy cost and carbon price). Technology selection in the power generation sector is implemented subject to electricity demand derived from end-use sectors, and carbon intensity of electricity also affects technology selection in the end-use sector with explicit carbon prices. Hence, end-use and power generation sectors are mutually interlinked (Akashi et al. 2011; Hanaoka et al. 2009; Oshiro/Masui 2014).

Several factors such as energy service demand, energy consumption, and energy efficiency in Japan and China are compared, and future pathways to reduce GHG emissions are examined based on the estimates by the AIM/Enduse model. It should be noted that as the technologies used in this analysis are either already available or are promising technologies in Japan, the costs could be overestimated, and that the actual shares of energy-efficient technologies and renewable energies could be underestimated under the Reference scenario without climate policies because climate policies are already being implemented and costs could be reduced much faster than expected.

7.3.1 Socio-economic Assumptions

Several socio-economic factors are assumed to project pathways towards an LCS using the AIM/Enduse model.

Table 7.1 Comparison of macroeconomic indicators and energy service demand for world, Japan and China

Indicator or sector	Energy service demand	Unit	World		Japan		China	
			2010	2050	2010	2050	2010	2050
Population*	–	(million)	6.932	9.171	127	102	1.362	1.426
GDP*	–	(trillion US $2005)	49	151	5	7	4	22
Industry*	Crude steel production	(million tons)	1.289	2.769	108	89	453	535
	Cement production	(million tons)	2.594	4.518	68	52	1.090	1.197
	Other industries	(Mtoe)[a]	1.928	5.079	78	90	399	1.208
Transport*	Passenger transport	(trillion passenger-km)	29	74	1.3	1.1	2.1	13.2
	Freight transport	(trillion ton-km)	18	44	0.3	0.2	2.7	9.8
Buildings*	Space heating	(Mtoe)[a]	1.891	2.655	48	60	157	1.944
	Space cooling	(Mtoe)[a]	400	803	19	26	49	588
	Hot water heating	(Mtoe)[a]	461	898	23	27	57	658
	Lighting	(Mtoe)[a]	718	1.389	53	68	69	202

Source UN (2009), Akashi et al. (2011) and Hanaoka et al. (2009)
Remark [a]Energy service demand in other industries and buildings as expressed in effective energy demand. Actual energy demand becomes less when energy efficiency of end-use technologies is improved

Table 7.1 shows a summary of the key socio-economic assumptions underlying the Reference scenario. Using the AIM/Enduse model, the Japanese and Chinese GHG emission pathways up to 2050 under the Reference and LCS scenarios were studied. In the Reference scenario, it was assumed that no additional climate policy will be implemented. Thus, there is no incentive to reduce GHG emissions specifically for climate stabilisation.

The medium variant of the World Population Prospects (UN 2009), in which the global population reaches 9.2 billion in 2050, was applied for the future population projections, with a Japanese population of 0.1 billion and a Chinese population of 1.4 billion. For economic growth, the annual global average growth rate was assumed to be 2.7 %, with the Japanese and Chinese growth rates assumed to be 0.9 and 5.0 %, respectively. The methodologies presented in Akashi et al. (2011) were used to make projections for the production of materials such as steel and cement. Using these methodologies, the projected global steel production in 2050 (2.8 Gt) was at the same level as the high-demand case in the IEA projection, while the projected cement production (4.5 Gt) was within the range of the high- and low-demand cases (IEA 2009a). The methodologies presented in Hanaoka et al. (2009) were used to make projections for transport demand, as well as for residential and commercial energy service demand. Compared with the high base-line scenario in the IEA study (IEA 2009b), the rate of increase of the projected transport volume was at the same level for passenger transport, but higher for freight transport demand.

It was assumed that nuclear power development follows countries' stated national plans (World Nuclear Association) except in the case of Japan, where it was assumed that nuclear power generation will be phased out by 2050. Regarding carbon capture and storage (CCS), it was assumed that the worldwide CO_2 storage capacity is approximately 4,600 $GtCO_2$. This value is the median of the estimated values from various studies (Dooley et al. 2006; Hendriks et al. 2004; IEA 2008, 2010a).

7.3.2 LCS Scenario to Meet the GHG Reduction Target

The LCS scenario was developed to analyse energy efficiency improvement towards low carbon development in Japan and China. The scenario was simulated by minimising the total global system cost under the constraint of reducing global GHG emissions by 50 % by 2050 relative to 1990 levels.

Figure 7.6 shows the cumulative additional costs under the LCS scenario compared with the Reference scenario for the world, Japan, and China. The results of the simulation suggest that it is technically feasible to achieve the GHG reduction

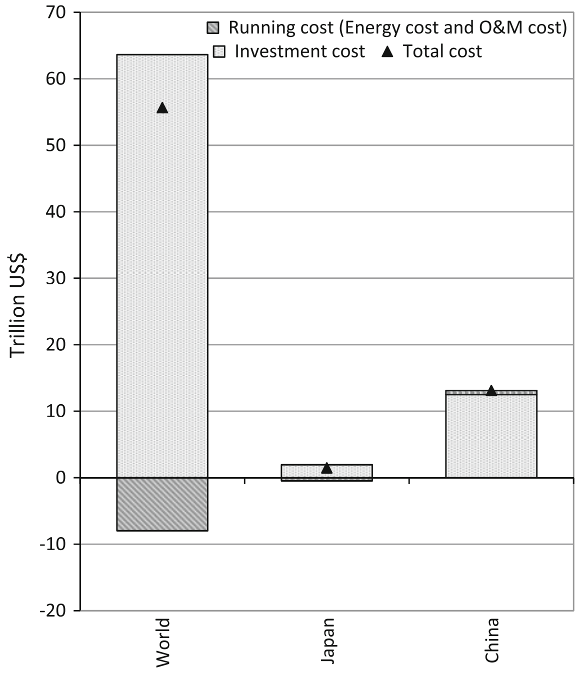

Fig. 7.6 Cumulative additional costs under the LCS scenario compared with the Reference scenario for the world, Japan and China. *Source* Authors' calculation

target. The world cumulative total investment cost required under the LCS scenario during the period 2005–50 will be approximately US$64 trillion higher than that under the Reference scenario. The running cost savings associated with energy-efficiency measures can offset the investment cost by $8 trillion, so the total net cost will be $56 trillion. In Japan, the investment cost is $2.0 trillion and the running cost savings can offset the investment cost by $0.48 trillion, resulting in a net cost of $1.5 trillion. In China, the investment cost is $13 trillion. This is about 20 % of the world total investment, and represents the largest amount for any country. China's running cost increases by $0.6 trillion, resulting in a net cost of $13 trillion. The running cost will increase despite the introduction of new, efficient technologies because the shifting of coal to natural gas occurs under the constraint of the GHG emission reduction target. The share of natural gas remains at 23 % in Japan, while that of China increases from 5 % in 2005 to 16 % in 2050. Switching from coal to natural gas has the merit of reducing air pollution in addition to the reduction of CO_2 emissions. China has already decided to shift from coal to gas from the standpoint of reducing air pollution.

Additional investment needs are dominant in the power generation sector, accounting for 57 % of the total additional investment in the world. The numbers are 70 and 60 % in Japan and China, respectively. The investment costs in the transport sector are the next highest cost in China, but can mostly be compensated for by the savings in running costs over the long term (Fig. 7.7). The increase in running costs of the industrial sector is high, partly because of the shift from coal to gas. Technologies, such as hybrid cars, inverter air conditioners, highly efficient gas-powered hot water heaters, and LED lights that are commonly used in Japan, could be introduced to increase energy efficiency and to slow down energy consumption.

The Chinese Ministry of Industry and Information Technology (MIIT) released a proposed fuel consumption standard for passenger cars. Under the proposed rule, the average fuel consumption of new passenger cars would fall to 5 L/100 km in 2020, as measured over the New European Driving Cycle (NEDC) from an expected fleet average of 6.9 l/100 km in 2015. The proposed Phase 4 standard

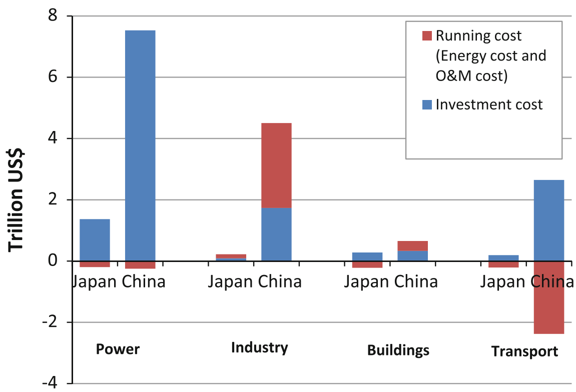

Fig. 7.7 Structure of additional investment needs between LCS and Reference scenario for Japan and China. *Source* Authors' calculation

would put China third, behind the EU and Japan, with respect to passenger car fuel consumption and equivalent GHG emissions requirements during the 2016–20 period (ICCT 2014).

GHG emission reductions are also higher in the energy supply sector, at 55 %, whereas energy demand-side measures contribute approximately 35 %. The remainder of the GHG emission reductions come from non-energy measures. The shares of the energy supply sector are 69 and 54 % in Japan and China, respectively, while those of the demand-side measures are 27 and 40 %, respectively (Fig. 7.8). China has a large potential for the reduction of CO_2 emissions if it applies new energy-saving technologies in both the supply and demand sectors.

Renewable energies such as solar, wind, biomass, and hydroelectric play a crucial role in power generation in 2050 (Fig. 7.9). The shares of renewable energy are 81 and 77 % in Japan and China, respectively. The shares of solar power generation are 25 % in Japan and 30 % in China, while those of wind generation are 8 and 17 %, respectively. Solar power and wind power plants have become competitive in China and could have further improvement to achieve the 2050 target. The contribution of CCS technology is also significant, accounting for a 9.9 % share of the total electricity generation in Japan and a 10 % share in China.

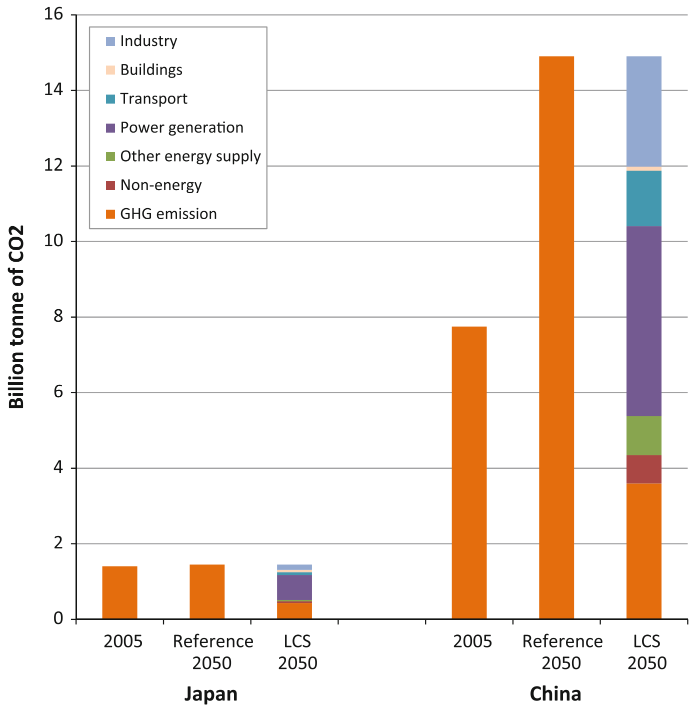

Fig. 7.8 GHG emissions in 2005 and two scenarios' results in 2050 for Japan and China. *Source* Authors' calculation

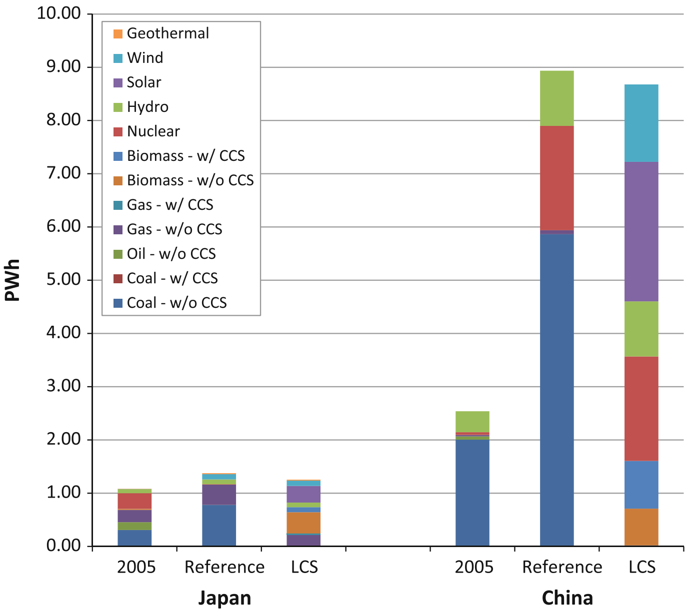

Fig. 7.9 Power generation mix in 2005 and two scenarios' results in 2050 for Japan and China. *Source* Authors' calculation

Figure 7.10 shows examples of projected shares of technologies in 2050 in the world, and cases in Japan and China. The share of high-efficiency heat pump boilers with a coefficient of performance (COP) of 6 will become 100 % and conventional passenger cars will be largely replaced by hybrid electric vehicles under the LCS scenario in China.

It is expected that energy efficiency will improve by 1.8 % per year in the world, 1.1 % per year in Japan, and 3.0 % per year in China from 2005 to 2050, with the annual GDP increases expected to be 2.7, 0.9, and 5.0 %, respectively (Table 7.2). In actuality, however, it is expected that more innovative technologies will appear and that the speed of energy efficiency improvement may be faster.

7.4 Opportunities and Challenges

Although the model analysis shows that a certain set of technologies can improve energy efficiency by 3 % per year and CO_2 intensity with respect to GDP by 3.5 % per year in China by 2050, implementation of the scenario is a big challenge and depends on a number of more specific conditions: rates of installation must be achievable; sufficient finance must be mobilised; and barriers to the adoption of low-carbon technologies must be overcome. There is also a possibility that more

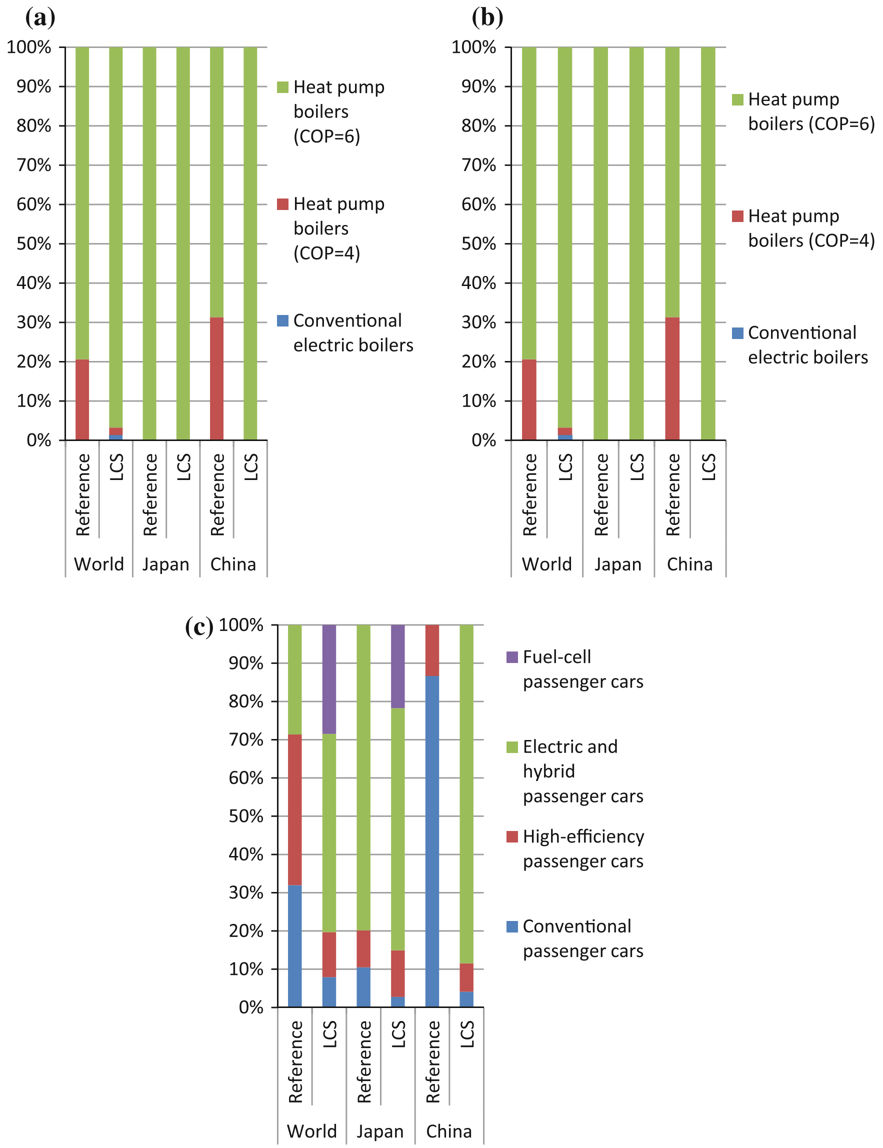

Fig. 7.10 Examples of projected shares of technologies in 2050 for the world, Japan and China. *Source* Authors' calculation. **a** Blast furnace. **b** Boilers. **c** Passenger car

innovative technologies will appear and that the speed of energy efficiency improvement may be faster. It should be emphasised that energy efficiency improvement has many co-benefits, such as increased energy security, reduced air pollution, and capacity-building for the development of new technologies (Kainuma et al. 2013).

Table 7.2 Macroeconomic indicator changes in LCS scenario from 2010 to 2050

	World (%)	Japan (%)	China (%)
GDP (%/year)	2.70	0.90	5.00
Energy/GDP (%/year)	−1.80	−1.10	−3.00
GDP/Energy (%/year)	−2.70	−2.40	−3.50

Source Authors' calculation

7.4.1 Strategies to Improve Energy Efficiency in China

The historical trend of energy efficiency in China shows a 3.0 % improvement over the 40-year period from 1971 to 2010 (EDMC 2014). From 2003 to 2005, there was a dramatic surge in the rate of increase of energy use in China, and widespread energy shortages occurred. Energy conservation and improvements in energy efficiency have been given high priority in China's energy development strategy for decades, and efforts to achieve energy conservation have already led to significant progress in energy efficiency. For example, energy efficiency improvements in the steelmaking industry have been driven by the diffusion of advanced technologies, with clear support from government policies. Despite these improvements, steelmaking in China remained about 20 % less efficient than that in Japan in 2003 (Jiang et al. 2006). However, the difference in energy efficiency between Japan and China is narrowing due to China's efforts in energy conservation (Jiang 2009).

To realise sustainable development, China's national energy development strategy incorporates an energy conservation priority policy, while at the same time the country is vigorously developing renewable energy and new energy sources (NDRC 2007; Jiang et al. 2007).

To promote the application of new energy and renewable energy over the long term, China has been giving financial subsidies and support to technical development. It has also been providing discounted loans for the development and use of small hydropower and wind power systems, in addition to implementing tax preferences and protective price policies (Li 2007). As a result, the country's energy efficiency began to improve significantly from 1980. From 1980 to 2000, the annual average energy improvement rate was 5.4 %. However, due to rapid industrial development since 2000, particularly in the area of energy-intensive products, energy efficiency improvement with respect to GDP has become negative (Jiang 2009).

At the US-China summit on 12 November 2014, the Chinese government, in a joint-statement, pledged that "China intends to achieve the peaking of CO_2 emissions around 2030 and to make best efforts to peak early". However, to peak in 2030 will not be sufficient in order to conform to its 2 °C target, and it requires additional efforts after 2030.

China's industrial output numbers for the first four months of 2015 showed decoupling of CO_2 emissions and economic development where industrial value added actually grew 6 % from January to April, coal output fell by 6.1 %, and power generation from coal, gas and other thermal plants fell by 3.5 %. Crude steel and cement outputs fell by 1.3 and 4.8 %, respectively, while higher value industries such as electronics and chemicals maintained high growth. The data suggests China's industrial and economic structure is undergoing not just a temporary slowdown but a rapid overhaul, profoundly changing the outlook for CO_2 emissions. At the same time as industrial output is becoming less carbon-intensive, energy production from low-carbon sources is increasing (Myllyvirta 2015).

The Energy Research Institute reports a path that will gradually reduce dependence on fossil fuels and transit to a high renewable energy penetration. According to their calculation, China's end-use energy consumption in 2050 will be 3.2 billion tce and electricity will account for 62 %. The primary energy supply will be 3.4 billion tce, of which 62 % will be from renewable energy. Energy consumption per unit of GDP will be 0.12 tce/10,000 yuan and energy efficiency will increase by 90 % from 2010 (ERI 2015).

The extension of these strategies could lead to another new long-term plan for the next 40 years to continuously improve energy efficiency by 3.0 % per year in order to meet the climate change target, although energy efficiency improvement will become difficult to achieve when energy efficiency is higher.

7.4.2 Financing for LCS

As discussed in Sect. 7.3, the cumulative total costs to achieve a 50 % emission reduction target over the period 2005–50 are estimated to be \$1.96 trillion and \$12.5 trillion in Japan and China, respectively. These are equivalent to costs of \$43 billion and \$278 billion per year in each country. A report by UNEP/BNEF (2013) estimates that investment in renewable energy in China reached \$66.6 billion in 2012. Therefore, financing will need to be scaled up by a factor of four. When viewed in the context of the total investment required, this is affordable considering the world's financial stock, which (including global stock market capitalisation) stood at more than \$210 trillion at the end of 2010 (Roxburgh et al. 2011). However, private capital will not be automatically mobilised to cover the costs of LCS technology R&D and deployment. For this reason, various measures such as the Climate Investment Funds, carbon pricing, feed-in tariffs, green building certificates, carbon offset markets, and private-public initiatives to lower barriers for investors are currently being implemented (UN 2010; World Bank 2011).

7.4.3 Supply-Side Challenges

The share of coal in China was 79 % in 2005. This figure will be 66 % in 2050 under the Reference scenario, but for climate stabilisation, coal power plants need to be phased out. The share of nuclear power in China in 2050 will be 23 % under the LCS scenario, although it might be lower because of the increased consideration of risk. It is assumed that nuclear power plants will be phased out by 2050 in Japan.

Under the LCS scenario, renewable energy will hold a share of 77 % in 2050, with solar PV, wind, and biomass accounting for 30, 17 and 18 %, respectively. China has already enhanced polices to introduce renewables from the standpoints of energy security and climate stabilisation. In order for renewables to reach a share of more than 50 %, innovative technologies need to be developed, such as storage systems and smart distribution systems. The establishment of a power grid system that is sufficient to secure the distribution of renewable energies is one of the major challenges in the supply sector.

7.4.4 Demand-Side Challenges

Energy efficiency improvement cannot be achieved only by government policies and industrial efforts. It also relies on the energy consumption practices of the public. If people do not use energy-efficient goods, there will be no incentive for enterprises to develop new energy-saving technologies. Typical examples are passenger cars and electric appliances. If people buy more energy-efficient cars and energy-saving appliances, this can be expected to lead to further improvements in their efficiency.

Strategies to offer incentives that affect individual choices are also required. Improving people's awareness through communication, education, and information-sharing is a prerequisite for reducing energy service demand, particularly in the buildings and transport sectors.

The possibility of a "rebound effect", whereby energy efficiency leads to lower costs and encourages greater use of energy services, must be considered when promoting demand-side measures. The economy-wide rebound effect caused by significant improvements in the productivity of energy-intensive industries could mean that more than 50 % of physical improvements could be offset by changes in economic activity (UKERC 2007).

Another point in demand-side management is related to infrastructure. Public transport systems are an example. To reduce CO_2 emissions from the transport sector, three strategies need to be considered: avoiding unnecessary travel demand; shifting transport modes to low-carbon types; and improving energy efficiency and emission intensity in transport. These strategies should be properly designed and implemented (Low Carbon Asia Project 2013).

7.5 Conclusion

China has implemented various policies to improve energy efficiency and reduce GHG emissions. The Chinese government set a target to reduce energy intensity by 20 % between 2005 and 2010 in the 11th Five-Year Plan and it is striking that an annual efficiency improvement of 4.2 % was achieved over the five-year period. China made a pledge to reduce its CO_2 emissions intensity per unit of GDP by 40–50 % by 2020 compared with the 2005 levels at COP16 and plans to reach its peak of CO_2 emission by 2030.

Japan struggled to reduce environmental pollutants in the 1960s and to decrease energy consumption to cope with the oil crises in the 1970s. For these ends, Japan developed high-efficient technologies and low-pollutant vehicles. These technologies have helped to improve living standards.

Energy conservation continues to be a national priority due to energy security, climate change and the need to reduce pollution in China as well as in Japan. If more innovative technologies are developed, energy efficiency improvement will be further promoted. This contributes not only to climate stabilisation, but also towards solving environmental problems.

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About this Book

China, with the largest markets and manufacturing factories in the world, plays an important role in global energy use and carbon emissions. China has made remarkable economic progress over the last decade, resulting in a sharp increase in its overall energy use and GHG emissions. In 2007, China overtook the United States as the world's largest emitter of CO_2 emissions. In 2010, China became the world's largest energy consumer. Many countries, international organisations and research institutes have realised the importance of understanding China's contributions to the world, and thus a large number of studies on China's energy and emissions issues have emerged over the last decade.

In China's 12th Five-Year Plan (FYP), the central government set a 16 % reduction target for national energy intensity and a 17 % reduction target for carbon intensity. On 25 January 2013, China's State Council further announced the "12th Five-Year Plan for Energy Development". The plan summarises the country's major achievements in energy development in the 11th FYP period (2006–10), and clarifies national energy policy priorities through an ambitious set of infrastructure and market targets in the 12th FYP period (2011–15). It also serves as a useful basis to benchmark China's progress in energy.

This officially released energy development plan not only identifies various aspects of energy challenges faced by the Chinese central/local governments, but also provides an opportunity to study how best to achieve green growth and a low-carbon transition in a developing country like China. The progress of China's carbon mitigation policies also has significant impacts on the ongoing international climate change negotiations. Therefore, both policy-makers and decision-makers in China and other countries can benefit from studying the challenges and opportunities in China's energy development.

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